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Fruit Production

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Fruit Production

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Preface

These scripts have been prepared for students studying horticultural courses at the Slovak University of Agriculture in Nitra whether coming under Erasmus+ or other international schemes or interested in studying themes related to fruit production in the English language. It aims at offering a broad spectrum of facts and information helping the reader to understand different issues including fruit plant botany and biology, environmental requirements, propagation of fruit plants, processes in fruit fruit plants resulting in the production of fruits as well as technological aspects of fruit crop cultivation. The latter include topics from pre-planting soil preparation and planting through soil management, fertilization, irrigation, and protection against various abiotic factors to fruit harvest and post-harvest handling. As such the scripts have encyclopedic character and serve as an introduction to the other subjects dealing with fruit production.

The content is based on long-term experience in the field of university education and cooperation with fruit producers. Cooperating experts Eva Nováková, editor of Sady a vinice magazine, Andrej Višňovský, owner of enterprise Podunajské orechy contributed with some of pictures as did colleagues from Plantext Veselé pri Piešťanoch, ltd. I express my gratitude also to unnamed authors of the pictures borrowed from our previous publications and internet sources.

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the author

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1 Importance of ruit production and classification of fruit crops

1.1 Importance and Benefits of Fruit Production

Fruit growing is one of the important and paying branches of horticulture. It has been practiced in different corners of the world since times. Art and science have now developed into one of the most deviled skillful and intensive forms of land utilization.

Fruits of different kinds are part of a human diet in all corners of the world whether fresh or preserved by different methods.

Fresh fruits are rich in saccharides – monosaccharides (fructose, glucose) are easy to digest by man and better than sucrose which is added to processed food products. However, the taste of sucrose is sweeter and its higher concentration can be found in peaches, apricots, and some plums. The concentration of saccharides varies depending form the fruit species, meteorological conditions during fruit development, ripening, and the degree of ripeness. Unripe fruits contain starch instead of simple saccharides, which are products of starch hydrolysis during the ripening process. The highest starch content is in chestnut fruits.

Fruit flesh is weak in fats, while seeds are rich in them. Hence, nuts are a rich source of fats (and energy) because the seed is consumed (around 60% of seed weight). These fats are valuable from the aspect of share of individual groups of fatty acids. The fat component of the seeds of some fruit species (sea buckthorn, currants) is particularly rich in compounds that positively influence human organisms, and those fruits are used in the food industry and pharmacy.

The protein content is low in general, with the highest values found in berry fruits (less than 1%) and chestnuts (6 – 8%), while the lowest in apples and pears (0,4% or so). Nitrogen compounds are concentrated in seeds in general.

Water content is from 75 to 90%, in nuts it is low. Fres and preserved fruits contain protective substances e.g. vitamins and minerals, though their content varies remarkably depending on the species. Vitamins of the B group (thiamine, ergocalciferol, niacin, pyridoxine) are found in nuts mainly. C vitamin (L-ascorbic acid) content is remarkable, the richest source are rose hips (240 – 3000 mg per 100 g of fruit flesh), sea buckthorn fruits (350 – 1220 mg per 100 g of flesh), black currant (96 – 400 mg per 100 g of flesh), cornelian cherry (100 – 200 mg per 100 g of flesh) and strawberry (33 – 105 mg per 100 g of flesh). Apples contain only 4 – 10 mg of C vitamin per 100 g of flesh and a few cultivars up to 30 – 40 mg. Some fruits are rich in beta-carotene (apricots, peaches, sea buckthorn, rose hips). Also vitamins K and PP can be found in fruits, and some other substances with protective capacity e.g. flavonoids, anthocyanins, Selen, and resveratrol. Apricots, sea buckthorn, peaches, and rose hips are a rich source of antioxidants – carotenoids, chokeberry, blackberries, blueberries, mulberries, apples, black currant, and other berry fruits – flavonoids, walnuts – Selen, blueberries, cowberries, cranberry, blue grapes – resveratrol. Superoxide dismutase, a valuable substance that slows down the ageing process is found in various fruits.

Mineral substances participate in keeping the acid-alkaline balance in the organism. Fruit as food has basic nature. Mineral content in fruits ranges from 0,24 – 1,16%, highest value found in strawberries, rowan, black currants, and plums.

The fibre contained in fruits is another valuable substance for the human organism. It is a complex of unsoluble and indigestible high-molecule substances (cellulose, lignin) and soluble ones (gums, slimes, pectins) with negligible nutritive value but a huge surface that helps to clean the organism. Due to that, dietary fibre has been at the centre of the attention of dietologists during recent decades. High content of fibre is found in apples and berry fruits (particularly unripe), rose hips, medlar, etc.

Organic acids in fruits are represented by malic acid predominantly (in pome fruits, stone fruits, cornelian cherry, and rowan fruits). In fruits of some species (pear, berry crops) citric acid prevails. However, the total acid content in fruits varies a lot: apples 0,2 – 1,6%, pears 0,1 – 0,5%, apricots and peaches 0,2 – 1,5%, plums 0,4 – 3,5%, sweet cherries 0,3 – 0,8%, sour cherry 1,4 – 2,2%, raspberries 1,0 – 2,0%, currants 2,3 – 3,7%, and gooseberries 0,9 – 2,3%.

Tannins cause an astringent taste in fruits. Their presence is manifested in unripe fruit mainly and in rowan, chokeberry, medlar, quince fruits, etc. The astringent taste disappears when the content of simple sugars increases, due to the effect of cold (starch hydrolysis). In the human organism, tannins influence vein flexibility and leakiness, inflammation processes, and the digestion system.

Aromatic substances are various substances belonging to acid esters, aldehydes, and essential oils. They cause pleasant, sometimes unpleasant fruit aromas. Aromatic and colour substances enhance the taste to eat.

Recommended fruit consumption per year is 100 – 150 kg, depending on age, weight, and composition of a diet.

Fruit growing has several economic advantages and non-economic benefits:

- per unit yields are high - well-maintained and established orchards bring better returns than many field crops. From a unit area of land, more yield/income is realized than in any of the agronomic crops. The average yields of some fruit species can be 10 to 15 times higher than those of field crops.
- high net profits – though the initial cost of the establishment of an orchard is high, it is compensated by higher productivity and/or due to the high value of produce.
- a source of fruit for fresh consumption or home processing sold via various channels (on-farm sales, self-picking, regional shops and markets, wholesale markets
- a source of raw material for the agro-based industries – the raw material for canning and preservation (fresh fruits), food processing (teas, beverages, dried fruits, fruit seed oils, pastry, et.), cosmetic, pharmaceutic industry, and also a production of furniture and wooden tools.
- efficient utilization of resources – while field crops are quite seasonal farmers have to solve the problem of occupying the employed people with other activities during slack seasons, fruit growing being perennial enables the grower to remain occupied throughout the year in different farm operations and utilize fully the resources and assets like machinery, in farm, land, water for production purpose through the year (depending on given climate and fruit species)
- utilization of waste and barren lands for production – although most fruit crops require good soils for production, there are many fruit crops humble in requirements and may be grown on poor, shallow, undulated soils considered unsuitable for growing field crops. Traditional farming proves uneconomic on wastelands. Some species require specific soils (acidic even drenched) which in general can not be used for field production.
- positive effect on export/import ratio – fruits are a common part of the diet recommended as a source of biologically active compounds. Due to that, if total fruit consumption is not satisfied with inland fruit production it requires import, while excessive production creates conditions for export to other countries.
- one-time capital investment – most of the fruit crops are perennial and hence, there is no recurring expenditure on planting and layout of a fruit orchard. In some situations, this may not be true, with increased production of the established orchard the necessity of building storage capacities can emerge for example.
- continuous flow of money – harvesting of many fruits lasts an extended period (due to the gradual ripening, or cultivars with the different ripening terms), and being highly perishable, they need to be marketed immediately after harvest. This provides a source

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of the continuous flow of inputs and other expenses of immediate nature compared to the crops which are harvested at once.

- fruit growing is possible in a backyard garden which helps to reduce the family budget on the purchase of fruits and in some countries influences the market for fruits.
- the growing of fruit trees and shrubs helps to maintain ecological balance and in big areas, it can influence microclimate. Fruit trees when grown on a big scale also generate economy.
- fruit tree farming also reduces soil erosion, silting tanks, and air pollution and fruit orchards contribute to CO_2 sequestration also.
- fruit production generates employment – fruit crop farming is a highly intensive and skillful enterprise, employment in fruit production, nursery production, fruit processing industries, research, breeding, education, services for fruit producers, etc. (jobs for persons with higher education also).
- flowering fruit plants are rich sources of bee food (pollen, nectar) mainly in the early season.
- fruit growing sector creates social bounds, and can be a basis for traditions (harvest fests, etc.).
- fruit farms in the combination of original fruit products show potential for agrotourism.

1.2 Economic classification of fruit crops

Fruit crops, in general, differ in growth habits, length of the life cycle, environmental requirements, technological requirements, and fruit type. These differences create the basis for crop classification. Based on growth habits, fruit types, and crop importance, fruit crops of the temperate zone can be classified as follows:

1. Fruit trees
- Pome fruit species
    - apple tree, pear tree, quince, medlar,
- Stone fruit species
    - plums – European plum, gage, damson plum, mirabelle plum, cherry plum, Japanese plum, and their hybrids,
    - cherries – sweet cherry, sour (tart) cherry, and their hybrids,
    - stone fruits with fuzzy skin – peach tree, apricot,
- Nuts
    - walnut, chestnut, hazelnut, almond,

2. Berry fruit species
    - currants, gooseberry, raspberry, blackberry, and hybrids of 2 previous – tayberry, loganberry, etc., strawberry,

3. Miscellaneous fruit crops
    - cornelian cherry, fruit roses, sea buckthorn, mulberry, cowberry, blueberry, cranberry, actinidias, chokeberry, elderberry, rowan, saskatoon, blue honeysuckle, etc.

Miscellaneous fruit crops are represented by very different species which, due to various reasons – low yielding capacity, specific technological or environmental requirements, fruits not suitable for fresh consumption, the short history of growing in given regions (new introductions), novelties in fruit crop assortment. The latter are represented by new interspecific and intergeneric hybrids of some common fruit species e.g. stone fruit species – aprium, pluot, plumcot, sprite, etc., hybrids of pome fruit species with their wild relatives, rowan hybrids, etc. These have enriched fruit assortment in recent years and can have better adaptability to different environmental conditions or higher disease resistance compared to traditional fruit crops.

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Picture 1 Pome fruit species – apple (Paulen)


Picture 2 Stone fruit species – plum (Paulen)

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Picture 3 Nuts – Persian walnut (Paulen)


Picture 4 Berry fruits – gooseberry (Paulen)

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Picture 5 Miscellaneous fruits – sea buckthorn (Paulen)

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2 Botanical classification of fruit crops

The assortment of fruit crops embraces species and lower taxa that belong to various families and many genera. Bellow, there is the classification of the crops grown in regions with temperate climate.

Family *Rosaceae* is the richest from the aspect of a number of species used for the production of fruit in the temperate climatic zone. The family is divided into sub-families, several (3) of them being represented by fruit crops differing in fruit types. In conditions of temperate zone (in Europe) the following taxa are grown or have economic potential:

Family: *Rosaceae*
Subfamily : *Prunoidae*
Genus : *Cerasus* DUHAM / Cherry

C. avium Wild cherry, bird cherry (rootstock and cultural form for fruit production)
- " - *subsp.avium* Sweet cherry
- " - *subsp.juliana*
- " - *subsp.duracina* Bigarreau cherry

C. vulgaris Tart cherry
- " - *subsp.vulgaris*
- " - - " - *var. vulgaris* Amarelo cherry
- " - - " - *var. austera* Morelo cherry
- " - *subsp.acida*

C. mahaleb Mahaleb cherry (used as a rootstock for cherries)


Picture 6 Sweet cherry tree (Paulen)

Genus : *Prunus* L. / Plum

P. domestica Common plum
P. insititia Damson plum

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- " - *convar.italica* Gage
- " - *convar.syriaca* Mirabelle plum
- " - *convar.pomariorum* Spilling
- " - *convar.insititia* Damson plum

P. cerasifera Cherry plum (mainly rootstock, cultivated for fruits in South-Eastern Europe and around Black Sea)

P. salicina Japanese plum

Genus : *Armeniaca* SCOP. / Apricot

A. vulgaris Common apricot


Picture 7 Japanese plum in blossom, columnar form (Paulen)

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Picture 8 Peach tree with fruits (Paulen)

Genus : *Persica* MILL. / Peach

P. vulgaris Common peach
- " - *subsp. vulgaris* Clingstone and freestone peaches
- " - *subsp. laevis* Nectarine

P. davidiana David´s peach (rootstock)

Genus : *Amygdalus* L. / Almond

A. communis Common almond
- " - *var. dulcis* Sweet almond
- " - *var. fragilis* Fragile almond
- " - *var. amara* Bitter almond

Subfamily : *Maloidae*

Genus : *Cydonia* MILL. / Quince

C. oblonga Quince
- " - *var.pyriformis* Pear-like quince
- " - *var.maliformis* Apple-like quince

Genus : *Pyrus* L. / Pear

P. communis European pear
P. pyrifolia Asian pear

Genus : *Sorbus* L. / Rowan

S. domestica Service tree
S. aucuparia subsp.moravica
European mountain ash (sweet-fruited form)

Genus : *Malus* MILLER / Apple tree

M. x domestica Apple tree (cultivated varieties)
= hybr. *M.sylvestris* and *M.dasyphylla*

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M. praecox (referred to as a synonym of *Malus* x *domestica,* rootstock for apple tree cultivars)

M. baccata Berry apple (breeding, source of resistance)

Genus : *Mespilus* L. / Medlar

M. germanica Common medlar

Genus : *Aronia* / Chokeberry

A. melanocarpa Black chokeberry

Genus: *Amelanchier* / *Serviceberry, Saskatoon*

A. alnifolia Pacific serviceberry

A. Lamarckii Juneberry

Subfamily : *Rosoidae*

Genus : *Rubus* L. / Bramble, individual names of species

R. idaeus Raspberry

hybrids with R. coreanus, R. crataegifolius, R. arcticus are also belong to raspberry group.

R. fruticosus Blackberry

hybrids with R. procerus, R. allegheniensis, R. rusticanus var. inermis also belong ro blackberry group.

Besides the previous, there are hybrids of raspberry and blackberry groups with different names e.g. tayberry, boysenberry, loganberry etc.

Picture 9 Blackberry – cultivated form (Paulen)

Genus : *Rosa* L. / Rose

R. villosa Apple rose

R. rugosa Rugosa rose, Beach rose

Genus : *Fragaria* L. / strawberry

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F. vesca var. semperflorens
Everbearing strawberry (with tiny fruits typical for wild strawberry)
F. x ananassa Garden strawberry

Other fruit species are distributed in several families with fewer fruit species in each of them:

Order : *Saxifragales*
Family : *Grossulariaceae*
Genus : *Ribes* L. / Currant
R. spicatum (syn. *R. multiflorum*)
Downy currant
R. rubrum Red currant
- " - *subsp. hortense* cultivated red and white currant cultivars
R. petreum Rock red currant
R. nigrum Black currant
R. aureum Golden currant (mainly rootstock for currant and gooseberry)
R. sanguineum Red flower currant (decorative currant species)

Genus : *Grossularia* MILLER / Gooseberry
G. uva-crispa Gooseberry
- " - *subsp. lasiocarpa*
- " - *subsp. reclinata*
Cultivated varieties with different fruit characteristics (fruit colour, fuzz presence on a fruit skin, etc.)

Order : *Ericales*
Family : *Ericaceae*
Genus : *Vaccinium* L. (there is no single name for this genus)
V. vitis idaea Dewberry, cowberry
V. myrtillus Blueberry (European), bilberry
V. corymbosum Highbush blueberry
Dewberry
Genus : *Oxycoccus* HILL / Cranberry
O. macrocarpus American cranberry

Order : *Cornales*
Family : *Cornaceae*
Genus : *Cornus* L. / Dogwood
C. mas Cornelian cherry, dogwood

Order : *Rubiales*
Family : *Caprifoliaceae*
Genus : *Sambucus* L. / Elder
S. nigra Common elder

Order : Juglandales
Family : Juglandaceae
Genus : Juglans L. / Walnut
J. regia Persian walnut, English walnut

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- " - *var.regia* variety with thin shell
- " - *var.germanica* variety with hard shell

J. nigra Black walnut (rootstock, wood, sometimes fruit)

Order : *Betulales*
Family : *Corylaceae*
Genus : *Corylus* L. / Filbert, Hazel

C. avellana	Common hazelnut, European hazel
C. maxima	Giant filbert, Kentish cob
C. colurna	Turkish filbert (rootstock for tree forms of previous species)

Order : *Fagales*
Family : *Fagaceae*
Genus : *Castanea* MILL. / Chestnut

C. sativa	Sweet chestnut, Spanish chestnut

Order : *Eleagnales*
Family : *Eleagnaceae*
Genus : *Hippophae* L / Sea buckthorn

H. rhamnoides	Sea buckthorn

Order : *Urticaless*
Family : *Moraceae*
Genus : *Morus* L / Mulberr

M. alba	White mulberry
M.. nigra	Black mulberry
M. rubra	Red mulberry

Order : *Ericales*
Family : *Actinidiaceae*
Genus : *Actinidia*

A. *chinensis*	Actinidia, chinese kiwi, golden kiwi
A. *deliciosa*	Actinidia, Kiwi, Kiwifruit
A. arguta	Tara vine, baby kiwi
A. kolomikta	Kolomikta vine

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3 Anatomy and morphology of fruit plants

Plant anatomy describes the internal structure of a plant and its organs. Working knowledge of plant anatomy is essential in:

- plant propagation via various methods – grafting, budding, division, cuttings, layering, tissue culture,
- pruning,
- performing hybridization as a basic process in plant breeding,
- diagnosing plant disorders.

Fruit plants grow as:

- trees,
- shrubs, bushes (berry fruits, brambles, cowberry), prostrate bushes (cranberry) or vines (actinidias),
- herbs (strawberries).

Morphology describes organs and parts of plants visible from the outside and gives them a name. At the whole plant level following principal organs are recognized – the root, stem, and leaf that belong to the group of vegetative organs, the flower, and the resultant fruit, which are reproductive (generative) organs.

3.1 Plant organs

3.1.1 Root

The root represents the underground part of a plant and has variable morphology (influenced by propagation method – generative, vegetative), rootstock species, and soil properties. There are two principal root system types distinguished e.g. allorhizic and homorhizic. Allorhizic root system develops from a primary root that produces one (or more) cylindrical main root (primary root) growing in the positively geotropic direction (reaches deep layers of soil profile) and lateral (secondary) roots growing more horizontally or in a slanting direction whereas homorhizic system consists of several to many slanting roots with more-less similar importance and thickness, produced from the basal part of the stem used for vegetative propagation.

Both the allorhizic and homorhizic system have advantageous and disadvantageous properties for a grower. Rooting depths are different according to root system type as well as rootstock. Allorhizic root systems reach deeper and require deeper soil preparation before planting, reacting less to irrigation and surface fertilization. Rooting depth thus influences performed soil cultivation, irrigation, fertilization, and support installation. Tree seedlings or generative rootstock have deeper rooting zone than vegetatively propagated plants with a homorhizic root system. Individual roots of some species can reach a depth of 3 or more meters, though the main mass of roots is distributed in a layer 0,2 – 0,5 or 0,6 m in generatively propagated rootstocks, 0,1 – 0,4 m in vegetatively propagated rootstocks, and 0,05 – 0,25 or 0,3 m in berry fruit species. Also, the diameter of the area inhabited by roots may be different. Some species root more planarly (rooting diameter 2 – 3 times bigger than crown diameter) e.g. cherries, plums, etc.

Root activity is influenced mainly by temperature, moisture, and soil properties (nutrients, humus, and aeration). Roots may be active at a temperature slightly above zero already when some metabolic processes take place, the minimum temperature for active root growth is from +4 to +8 ^{o}C depending on species, and the optimum temperature for root activity in fruit species originating in the temperate zone is 15 – 20 ^{o}C. Root activity starts earlier (by a few days to weeks) than vegetative growth of the aboveground system and finishes later than the activity of shoots (a few weeks or just before soil freezes) and has 2 maxima (from March to May-June, and from August or September to October). The distribution of root activity during a year is influenced by the climate, naturally. Species from warmer climatic zones grown

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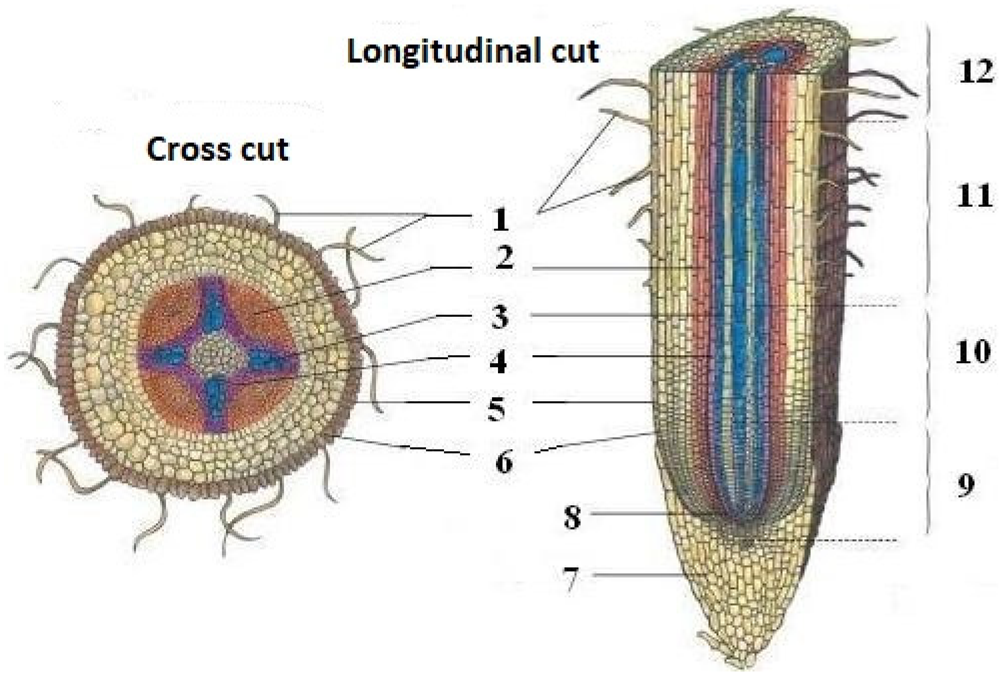
in temperate regions (peach, walnut, etc.) have only one maximum of activity – from the beginning of a season to the end of May – June, root activity decreases then until leaf fall.

For cross-cut and longitudinal-cut anatomy of the root look at the picture below



Picture 10 Cross and longitudinal cuts of root (modified by the author)
1 – root hairs, 2 – floem, 3 – xylem, 4 – cambium, 5 – bark, 6 – rhizodermis, 7 – calyptra, 8 – apical meristem, 9 – embryonal zone, 10 – elongation zone, 11 – differentiation zone, 12 – absorption zone

The constituent parts of the root have different placements within the organ but different functions also:

Epidermis – an outer layer of cells – a skin of a young root dying later, separates the internal part of a root from the surrounding environment.

Root hairs – Absorptive unicellular extensions of epidermal cells of a root in its young part. These tiny, hair-like structures function as the major site of water and mineral uptake. Root hairs are extremely delicate and subject to fast desiccation when exposed to open air. Root hairs are easily destroyed in transplanting.

Rhizodermis (cortex or root primary bark) consists of two layers:

Exodermis – primary tissues of a root bound on the outside by the epidermis and on the inside by the endodermis (together with endodermis it constitutes the primary bark of a root).

Endodermis – a single layer of cells in a root that separates the cortex tissues from the pericycle.

Pericycle (pericambium) – primary tissue – a layer of cells immediately inside the endodermis. It is a latent meristem of a root, in which cambium and phellogen (secondary meristems) are formed. Lateral roots arise from the pericycle.

The vascular system is located in a stele (central part of a root) – a bundle of xylem and phloem tissues – sieve-tube elements in phloem tissue conduct products of photosynthesis from leaves throughout the plant including down to the roots while vessels and tracheids in xylem tissue conduct water and minerals up from the roots up through the plant

Root functions are as follows:

- anchoring and supporting the plant – a mechanic function,
- absorbing and conducting water and minerals – absorption and conduction functions,

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- storing the products of photosynthesis (carbohydrates, sugars, proteins) – a storage function,
- metabolism – some organic compounds are produced in roots because roots have CO_2 assimilation capability – metabolic function,
- plant propagation by roots is possible if there are located adventive buds on them. Damaging the root provokes arising shoots (suckers) from those buds which can be used to obtain new plants – propagation function.

3.1.2 Stem

Stem forms an aboveground vegetative system and, depending on the growth habit, it forms different formations e.g. trunk and crown (trees) composed of different branches and shoots. Shrubs do not form trunks and ramification occurs from the soil level. Typical stem-based formations are as follows:

Trunk – unbranched part of the tree starting at the soil level and finished with branching at the crown base.

Central leader – the main stem of the tree from which other branches develop. In most cases, it prolongs the trunk.

Lateral (branch) – a branch originating from the main branch axis.

Multiple stemmed plants – plants with more than one stem arising from the base compared to plants with only a central leader (mainly in decorative trees, but also some bigger shrubs)

Permanent branch – a branch that is part of the major growth habit of the tree, usually originating from the trunk.

Scaffold branch – a permanent branch originating from the trunk or central leader and becoming a part of the major branching or framework of the tree. Scaffold branches may be distributed in clumps (floors) or without visible grouping.

Semi-scaffold branch (rib) – thinner branches growing on scaffold branches and filling space between scaffold branches. On semi-scaffold branches, there are born fruiting formations that bear flower buds and are variable according to the fruit plant species.

Sucker – a vigorous shoot originating from root or stem tissue located below ground.

Temporary branch – a branch usually originating from the trunk that is removed by pruning after permanent branches have been selected.

Terminal – tip end or shoot prolonging branch axis.

Water sprout (water shoot) – vigorous shoot arising from the trunk or older branches if the balance within the tree is disturbed. Similar shoots produced around wounds after pruning or hard damage are qualified as regenerative shoots.

Competing shoot (codominant shoot) – arising from the bud just below terminal one, growing in a similar direction as terminal shoot and competing with it for water and nutrients. Typically, one of them, either terminal or competing shoot, is removed or inhibited with pruning or there is a risk of developing a narrow crotch that is unstable later.

Basic shoot – a shoot arising from the base of a shrubby plant with the role of forming new branches and replacing senescent ones.

Proleptic (preformed) shoot – a shoot whose basis was formed in a previous season, within the so-called winter bud, and arises from it after a dormant period. It refers to a primary shoot.

Sylleptic (neoformed) shoot – a shoot that arises from the axillary bud on a previously formed shoot at the same season, typically later in a season spontaneously or after pinching of a growing shoot. It refers to secondary or tertiary shoot.

Shoots are composed of shorter sections called internodes bordered by nodes (obviously slightly swollen part of the stem). On a node, there is a leaf attached with one (a few sometimes) axillary bud.

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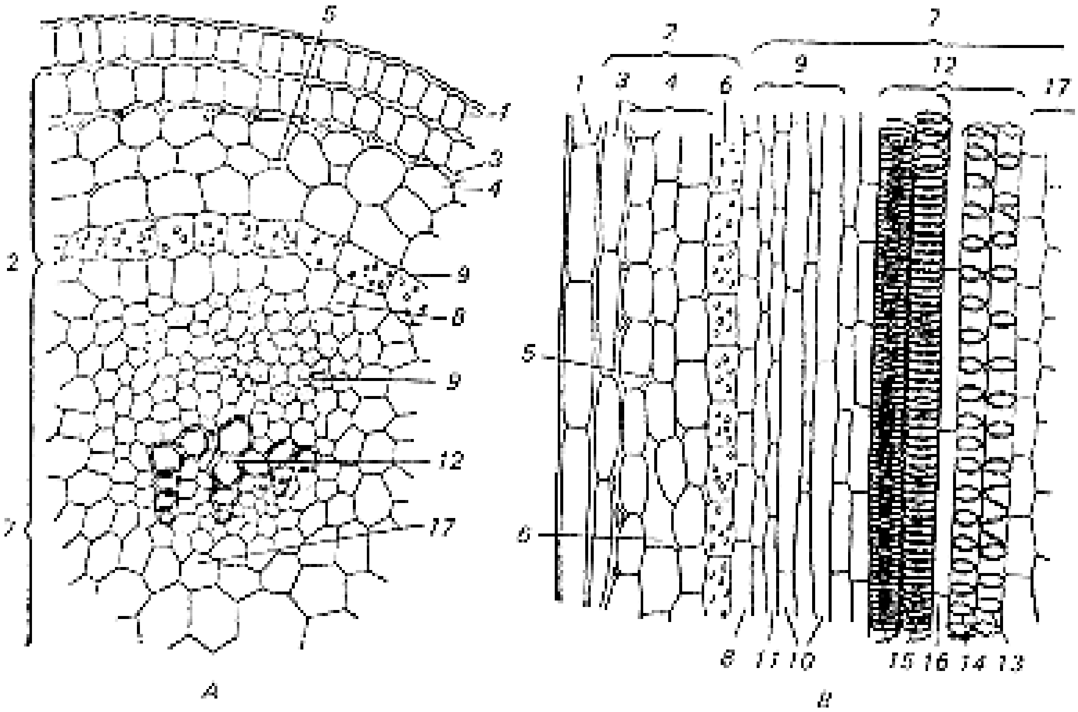
At the top part of a shoot, there is an apical meristem (referred to as the embryonal zone), followed downwards by a prolongation zone, and a differentiation zone. Unlike the root, stem prolongation growth continues longer, even with leaves and axillary buds already formed. The growth activity of stems in the temperate climate has 2, rarely 3 peaks (growth flushes) e.g., from leaf rosette formation until the first decade of June, from the second half of June until the first half of August, and possibly from late August until late September. The latter is not desirable cause interferes with the maturation of tissues and assimilates accumulation.

Cross-cut anatomy of the stem is like that of the root. The surface of the young stem is covered with skin (epidermis), with openings for gas exchange between skin cells. The skin of the young stem may be pubescent. Under the skin, there are a few layers of cells forming the primary bark (cortex) – outer part (exodermis), and inner part (endodermis). The primary bark is separated from the central column by a pericycle of which the secondary meristems are derived – (vascular) cambium producing secondary xylem with vessels and tracheids to the inside and secondary phloem with sieve-tube elements to the outside, and phellogen which produces cork cells to the outside. The epidermis and cortex are dying as the stem thickens. For crosscut anatomy look at the picture below.



Picture 11 Crosscut and longitudinal structures of stem (modified by the author)
1 – skin (epidermis), 2 – primary bark layer (cortex), 3 – collenchyma, 4 – parenchyma
5 – intercellular
cavities
6 – endodermis
7 – central cylindre
8 – pericycle
9 – protophloem
10 – phloem
11 – phloem cells
12 – xylem cells
13 – 15 – vascular bundle
16 – cells with thickened walls
17 – pith

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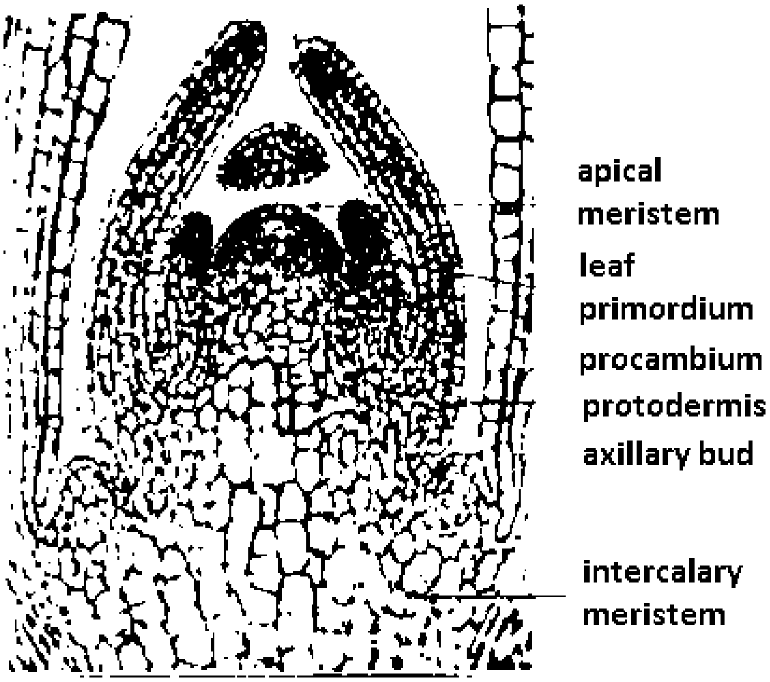
Vascular cambium has two main periods of increased activity in moderate climate e.g. from the start of the vegetation period to mid-June (1st), and from late June to late August or the beginning of September (2nd). These coincide with the growth flushes (see above). At the period of increased activity, the bark separates from the wood easily and there is a typical period for the budding of fruit woods in a fruit nursery. For longitudinal-cut anatomy look at the picture below



Picture 12 Longitudinal cut of the top part of the stem (modified by the author)

Stems have several functions which are:

- building the above-ground part of the plant, support for and the elevation of the leaves, flowers, and fruits. The stems keep the leaves in the light and provide a place for the plant to keep its flowers and fruits,
- transporting fluids between the roots and the shoots in the xylem and phloem,
- storage of nutrients and substances – mainly in older stems, materials are stored and used in cases of necessity – to start new growth in spring or after hard pruning or mechanical damage,
- metabolism – some substances are produced and transformed in stems,
- propagation of a plant – stem can root when in contact with soil even without the help of man, vegetative propagation of plants is performed with parts of stem obviously (cuttings, grafting, budding).

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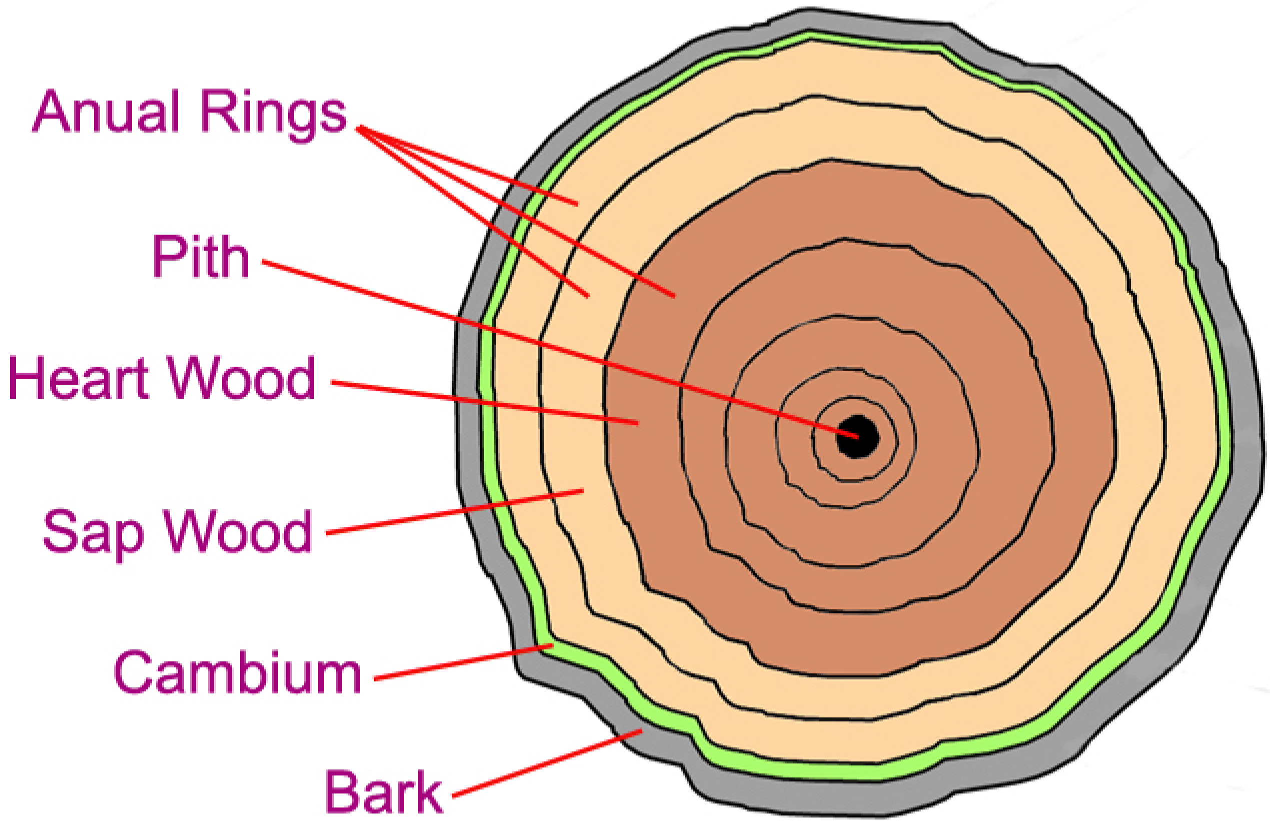

Figure 13 Secondary structure of stem (modified by the author)

3.1.3 Leaf

Leaves are the main assimilating organs of fruit plants. Typically, a leaf is a thin, flattened organ borne above ground and specialized for photosynthesis. The internal organization of most kinds of leaves has evolved to maximize exposure of the photosynthetic organelles, the chloroplasts, to light and to increase the absorption of carbon dioxide. Most leaves have stomata on the bottom side, which are open or narrow to regulate the exchange of carbon dioxide, oxygen, and water vapour with the atmosphere.

The functions of leaves are as follows:

- metabolic – production of organic compounds via photosynthesis, and respiration accompanied by the decomposition of organic compounds to water and CO_2 and energy release,
- storage of metabolites for a short period and their transport within the leaf to other parts of the plant,
- thermoregulation – via transpiration leaves are cooling plant tissue, and with the transpiration stream the leaves enhance absorption and transport of nutrients.

According to their positions leaves may be:

- alternate – the leaf attachments are singular at nodes, and leaves alternate directions, to a greater or lesser degree, along the stem,
- opposite – the two structures, one on each opposite side of the stem, typically leaves, branches, or flower parts. Leaf attachments are paired at each node and decussate if, as typical, each successive pair is rotated 90° progressing along the stem.

The leaf consists of a petiole (may be absent in some species e.g. honeysuckle) and a leaf blade. At the base of the leaf petiole, a pair of stipules may occur which have photosynthetic potential, and on the petiole of some species, there are glandules able to produce

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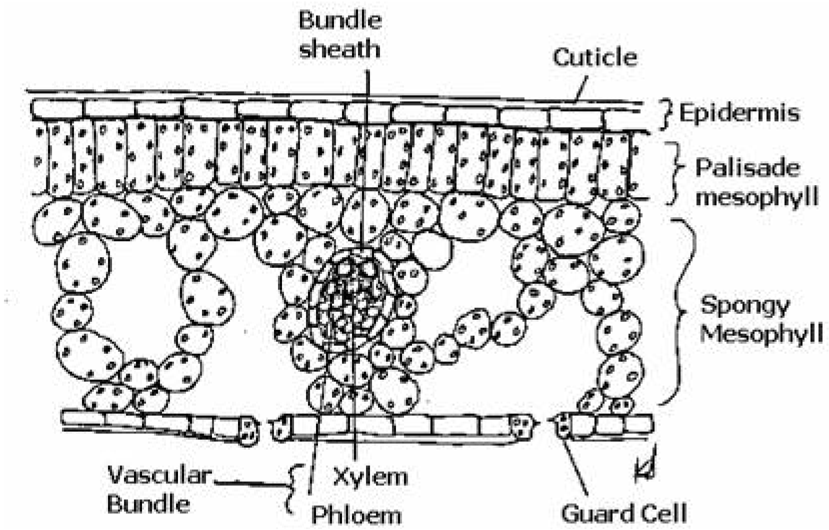
liquid containing sugar attracting insects. According to a leaf blade leaves are classified as a single blade or composed of leaflets – trifoliate or odd-pinnate (strawberry, walnut, service tree, raspberry, blackberry, fruit rose).

For leaf anatomy look at the picture 14 below.



Picture 14 Leaf anatomy (modified by the author)

3.1.4 Flower

Sometimes known as a bloom or blossom, it is the reproductive structure found in flowering plants. The biological function of a flower is to enable reproduction, usually by providing a mechanism for the union of sperm with eggs. Flowers may facilitate outcrossing (fusion of sperm and eggs from different individuals in a population) or allow self-fertilization (fusion of sperm and egg from the same flower). Some flowers produce diaspores without fertilization (parthenocarpy).

A stereotypical flower consists of four kinds of structures attached to the tip of a short stalk. Each of these kinds of parts is arranged in a whorl on the receptacle. The four main whorls (starting from the base of the flower or lowest node and progressing upwards) are as follows:

- calyx – the outermost whorl consisting of units called sepals; these are typically green and enclose the rest of the flower in the bud stage, however, they can be absent or prominent and petal-like in some species,
- corolla – the next whorl toward the apex, composed of units called petals, which are typically thin, soft, and coloured to attract animals that help the process of pollination,
- androecium – the next whorl (sometimes multiplied into several whorls), consisting of stamens. Stamens consist of two parts: a stalk called a filament, topped by an anther where pollen is produced by meiosis and eventually dispersed,
- gynoecium – the innermost whorl of a flower, consisting of one or more carpels. The carpel or multiple fused carpels form a hollow structure called an ovary, which produces ovules internally. The gynoecium of a flower is also described as a pistil consisting of an ovary, style, and stigma. The sticky tip of the pistil, the stigma, is the receptor of pollen

Both sexual organs (stamens and pistils) are contained in flowers classified as perfect. The imperfect flower contains only parts of one sex – pistil (female flowers) or stamens (male flowers). Imperfect flowers of both sexes may be positioned on the same plant – monoecious plants (walnut, chestnut, hazelnut) or different plants – dioecious male and female plants (*Actinidia* sp., sea buckthorn).

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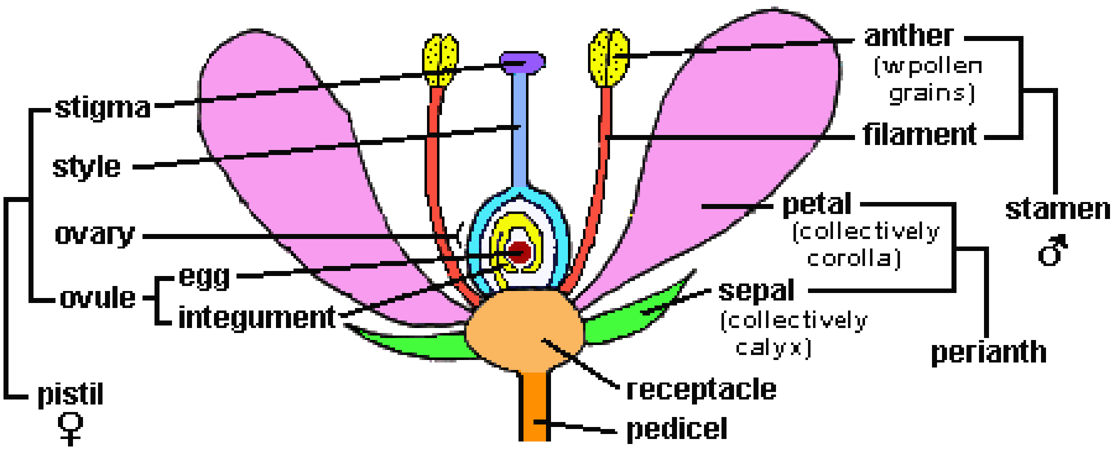

Picture 15 Flower anatomy (modified by the author)

3.1.5 Fruit

Fruit is typically produced after pollination and successful fertilization of female sex cells by pollen, and contains seed. In some cases, deviating from this rule, the fruit is seedless. There are different fruit types of fruit crop species, some are produced by a single ovary, some are aggregated fruits, and some are the product of the development of other parts of the flower, not only the ovary. According to it, there are classified:

- apocarpous fruits develop from a single flower having one or more separate carpels, and they are the simplest fruits,
- syncarpous fruits develop from a single gynoecium having two or more carpels fused,
- multiple fruits form from many different flowers.

Fruit wall (pericarp) consists of 3 layers of cells:

- exocarp (epicarp) – skin,
- mesocarp – flesh, mostly consumed part of a fruit,
- endocarp – layer proximately situated around seeds, often woody (stone).

Different fruit types differ in various characteristics:

Dry fruits

- achene – most commonly seen in aggregate fruits (e.g. strawberry),
- fibrous drupe (walnut)
- nut (hazelnut)

Fruits in which a part or all the pericarp (fruit wall) is fleshy at maturity are simple fleshy fruits. Types of fleshy, simple fruits are:

- berry (currant, gooseberry, cranberry, Actinidia)
- stone fruit or drupe (plum, cherry, peach, apricot)

An aggregate fruit develops from a single flower with numerous simple pistils:

- pome fruits (accessory fruits) of the family Rosaceae, (including apples, pears, and rowan) are a syncarpous fleshy fruit, a simple fruit, developing from a half-inferior ovary.
- rosehip (accessory fruit) with achenes (individual fruits) positioned inside tubular fleshy hypanthium.
- the aggregate fruit of drupelets with a prolonged receptacle

Multiple fruits – produced from inflorescence and individual fruit merged.

- mulberry – achenes in fleshy perianth on common inflorescence spindle.

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4 Generative processes in fruit plants

Because the aim of fruit growing is the production of fruits, and fruit is a result of generative processes, understanding those processes is an important part of the fruit grower´s knowledge. It is important not only because generative processes are the pre-condition of fruit forming, but in specific situations, fruits with specific characteristics (for example seedless fruits) may be produced. For nurserymen who need seeds for generative propagation the production of good-quality seeds is of utmost importance. For breeders, selection of compatible parents is important while knowing pollination biology is used during the hybridization process.

4.1 Pollination and fertilization

Within the processes leading to fruit formation a pollination is the first – transfer of pollen grain from anthers onto the stigma of the pistil which, in fruit species of the temperate zone can be performed with bees or other insects (pollinators, plants pollinated this way are known as entomophilous) or with a wind (those plants are known as anemophilous). In this sense pollination is a "technical" process in which biological components are taking place. Pollination with the own pollen is known as self-pollination which can be classified as pollination with the pollen within the same flower (autogamy), and pollination with the pollen coming from the other flower of the same plant (geitonogamy). Fertilization is the second process – after pollination the substances in the stigma make pollen grains germinate and grow through style to the ovary, and after that to fertilize egg cells (oosphere). Hence fertilization is a biological process.

There are the following categories of pollination/fertilization:

- auto-fertility (self-compatibility, self-fertility) – ability to be fertilized with own pollen (that of the same plant or coming from another plant of the same cultivar). For the farmer, it has many advantages and auto-fertile cultivars are preferred,
- auto-sterility (self-incompatibility, self-sterility) – the inability to be fertilized with own pollen. In nature, autosterility is a more frequent category than the previous one because it supports genetic diversity and the evolution of taxa,
- facultative autofertility – the ability to be fertilized with own pollen but the fertilization with foreign pollen (of another cultivar) is more successful - the number of pollinated egg cells (seeds) is higher, and fruits may be bigger.

Because of the biological advantage of pollination with foreign pollen, there were developed different barriers preventing self-pollination:

- monoecy – imperfect flowers (male and female ones) are born on the same plant (walnut, hazelnut, chestnut)
- dioecy – imperfect flowers of different sexes are born on different (male and female) plants. In the orchard, there must be planted plants of both sexes (sea buckthorn, Actinidia)

Different times of flowering – protogyny, protandry (earlier flowering of female or male flowers respectively in monoecious plants), space isolation (in monoecious, dioecious plants, or distant position of stamens and stigma in perfect flowers)

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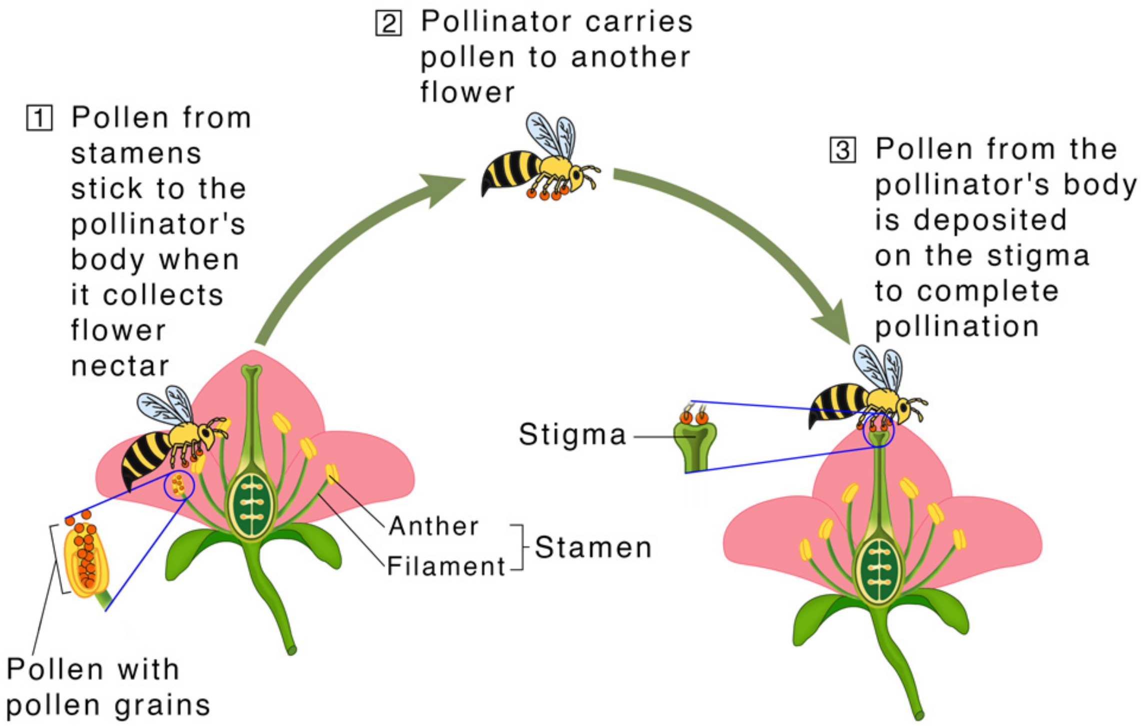
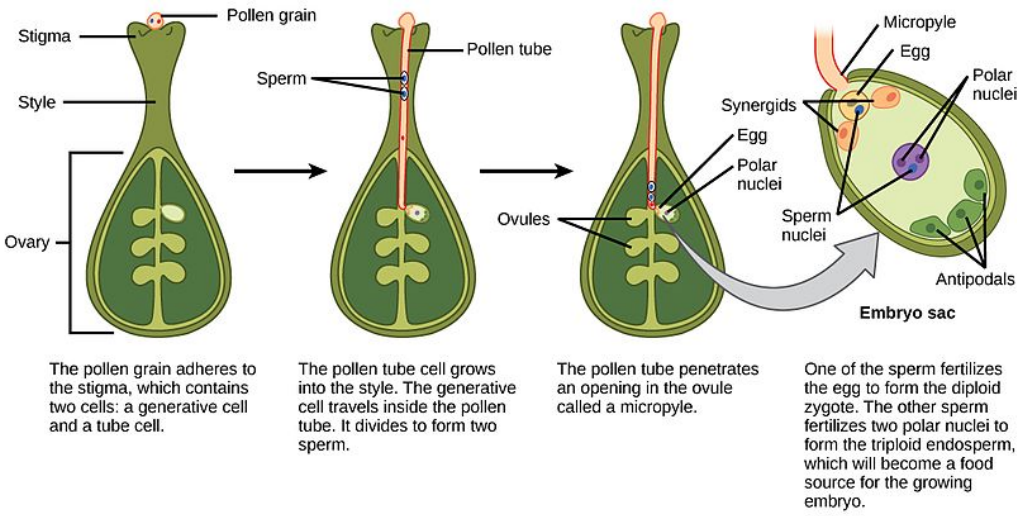


Picture 16 Pollination scheme in steps (ScienceFacts.net, modified by the author)



Picture 17 Fertilization scheme in steps (modified by the author)

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Picture 18 Female (in the centre) and male (laterally distributed below the top) inflorescentia of chestnut – monoecy (modified by the author)

4.2 Parthenocarpy and apomixis

Apart from regular (normal) categories, there are processes and situations which are not in coincidence with any of them. Sometimes, those processes may be exploited to produce fruits or seeds with a specific quality.

Parthenocarpy means fruit development without fertilization. The fruit resembles a normally produced fruit but is seedless. Sometimes, fruits may have different shapes due to different amounts of phytohormones during fruit development. Seedless parthenocarpic fruit can be induced in cultivars with a lower or higher tendency of parthenocarpy by the kind of artificial pollination with dead or altered pollen, or by pollen from a different plant species. The application of synthetic growth substances in paste form, by injection or spraying, also causes parthenocarpy development. Of the temperate fruit species, parthenocarpy naturally occurs in pears and apple trees.

The following conditions are contributing to the natural occurrence of parthenocarpy and the ability to bear seedless fruits – rich nutrition with fertilizers, good plant condition (strong vigour), a situation when late frosts occurred and killed flowers, single cultivar orchards preventing cross-pollination. Besides true parthenocarpy, it may occur mock parthenocarpy – stenospermocarpy (embryo produced from the fertilized oosphere dies during fruit development and only embryo coats are left in the fruit flesh – mostly grapes)

Apomixis is the development of fruit with seeds without fertilization. Apomixis results from changes in the female reproductive pathway such that female gametes develop without meiosis and embryos develop without fertilization from special generative tissues. In this sense, it is asexual reproduction. There are the following types of apomixis:

- parthenogenesis – the embryo is formed from a non-fertilized egg cell that had not passed meiosis (diploid embryo with the same gene set as mother plant) or had passed meiosis (haploid embryo is produced),
- apogamy – the embryo is produced from special cells of generative tissues (antipods or synergids) and is diploid,
- adventive embryony – seeds are produced from cells of nucellus (the central portion of an ovule in which the embryo sac develops). Within one seed coat there may be situated more embryos (polyembryony) of which one is a product of normal fertilization while other are embryonic),
- vegetative embryony (production of vegetative embryos developing into plantlets (f.e. bulbils in garlic etc., not frequent in fruit plants).

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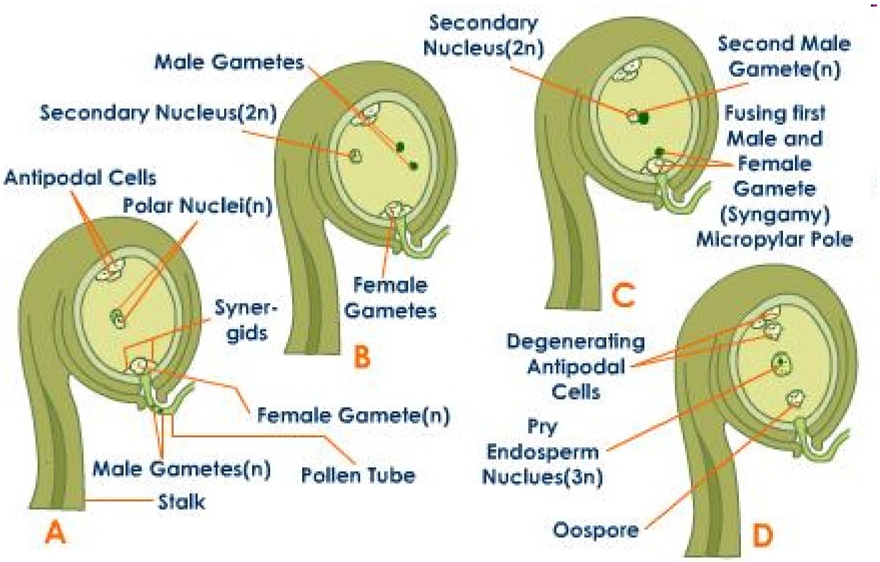
Apomixis is reported in apple trees, walnuts, and strawberries. In Central Europe, it is not exploited practically. In general, it helps to produce more fruits in conditions where pollination is a problem.



Picture 19 Structures playing a role in apomixis (modified by the author)

4.3 Sterility

Sterility is another phenomenon that can influence the results of fruit growing. Fruit plant sterility may be understood as:

- sexual reproduction disability (fruit with seeds are not produced) – a biological view
- yield absence (fruits are not produced) – more-less economic view

There are different types of sterility, and some of them may be avoided by proper growing technology. There can be classified following types of sterility:

a) morphologically caused – functional part of sex apparatus is missing or does not work properly (anthers are not opening or not well developed for example),
b) cytologically caused – 3n (triploid) genotypes show problems in meiosis and the sex cells do not contain complete sets of chromosomes hence they are not viable. This type of sterility is manifested in species with 1 seed in the fruit – fruits can´t develop, while in species with more seeds in the fruit, it may develop with fewer seeds and triploidy causes big production of assimilates which enhances such fruit development. The share of viable pollen grains is very small however and triploid cultivars can´t be used as a source of pollen for pollination. Triploid cultivars are available in apple tree (Jonagold, Mutsu, Boskoop, etc.) and pears (Beurre Lucas, etc.) and are fruitful,
c) genetic male sterility – pollen germination inability caused by the presence of genes of sterility. These genotypes may not be used as a source of pollen, but fertilized with the viable pollen,
d) induced environmentally – by environmental factors (frosts during blossom, drought, lack of nutrients during the period of flower bud differentiation, etc.), or time as a factor (seed of extra early cultivars of stone fruits is not fully developed in the harvest period),
e) Physiologically caused – with genes causing mutual or unilateral incompatibility (pollen of some cultivar does not germinate on the pistil of another cultivar, while with others the process runs without problems).

4.4 Fertilization characteristics of individual fruit species

Below, there are indicated possible alternatives of fertilization characteristics found in different fruit crops.

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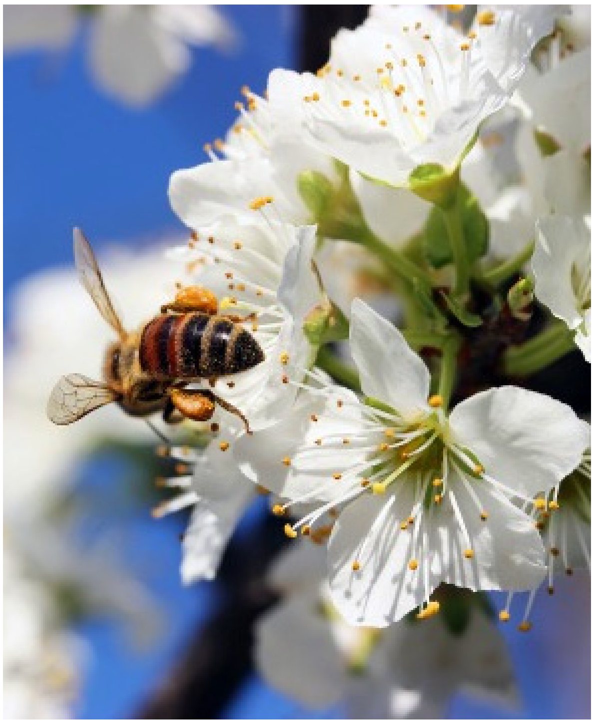
- Apple tree – self-sterile, facultative self-fertility (Golden Delicious, Ontario), cytologically caused sterility (3n cvs. Mutsu, Jonagold, Boskoop), physiologically caused sterility (also among cultivar and its clones),
- Pear – self-sterile, cytologically caused sterility, physiologically caused sterility (cvs. clones), parthenocarpy
- Asian pears – self-fertile to self-sterile, physiologically caused sterility occurs among cultivars,
- Quince, medlar – self-fertile,
- Sweet cherry – self-sterile in general, self-fertile cultivars – Stella, Celeste, Lapins, Skeena, Sweetheart, Sunburst, etc., physiologically caused sterility: incompatible groups – 1. Karešova, Troprichter, Van, 2. Granat, Kordia, 3. Bigarreau Napoleon, Starking Hardy Giant, 4. Bigarreau Napoleon, Lambert, Bing,
- Tart cherry – mostly self-fertile, also other concepts occur,
- Plums – self-fertile, some facultatively self-fertile, also self-sterile, morphologically caused sterility (Tuleu Gras),
- Apricot – self-fertile, some cvs. facultatively self-fertile (Veecot, Ceglédi óriás, Ligeti óriás a i.) or self-sterile, gradual flowering (Vegama, Rakovsky),
- Peach – self-fertile, morphologically caused sterility (J.H. Halle),
- Almond – self-sterile to facultatively self-fertile,
- Walnut – anemophilous, self-sterile (protogyny, protandry), seldom self-fertile (when homogamy occurs), apomixis,
- Chestnut, hazelnut – anemophilous, self-sterile to facultatively self-fertile (protogyny, protandry),
- Raspberry, tayberry – self-fertile,
- Blackberry – self-fertile, often facultatively self-fertile, or self-sterile,
- Currants – red, white – self-fertile, black – various degrees of self-fertility,
- Gooseberry – self-fertile, parthenocarpy (though unimportant from productive point of view),
- Strawberries – self-fertile, seldom morphologically caused sterility,
- Actinidia – dioecious or with perfect flowers (some cvs.),
- Mulberry – monoecious to dioecious,
- Sea buckthorn – dioecious, anemophilous,
- Elderberry – self-fertile,
- Cornelian cherry – self-sterile.

4.5 Pollination in fruit plantations

Pollination by insects requires the presence of pollinating insects and suitable meteorological conditions (mainly temperature, calm, and without rain). However, it can be enhanced by the following measures:

Placing beehives in the orchard – 2 – 4 per beehives per ha, in trees with many flowers and short blossom period (cherries) up to 10 beehives per ha. Beehives should be delivered and placed in the orchard before the blossom period, based on an agreement with a beekeeper.

Bumblebees – bumblebees are a relatively new introduction to fruit orchards commercial pollination. They are delivered in hives with three families (Tripol). Two Tripols are recommended per ha. In the glasshouse production of strawberries, bumblebees are used as exclusive pollinators, and also the other fruit species grown under cover may benefit from their use. The advantage of bumblebees is that their activity starts at a temperature lower than that required by bees and may work in worse weather (cloudy, windy). Bumblebees are not selective, hence visit flowers of different species during the same flight (if flowering weeds present in the orchard). Bumblebees are also insensitive to the varroa mite which is a dangerous pest of bees. The natural occurrence of bumblebees may be enhanced with the use of wildflower lawns in orchards and around orchards, leaving hedgerows uncut with plenty of flowering plants. The introduction of clover (*Trifolium*,), vetches (*Viccia*) helps also while some growers use strips planted with lavender (*Levandula* sp.). Commercially supplied bumblebee colonies survive only a few weeks when placed in glass- or plastic houses, longer in open



Picture 20 Honeybee – a major pollinating insect in Central Europe (modified by the author)

Picture 21 Bumblebee – a naturally occuring pollinator in many countries (modified by the author)

Solitary bees encouraging – solitary bees are inhabiting natural areas and build their nests in soil or hollow weed stems. Intensive cultivation practices and low-diversity plantations decrease the abundance of these insects. To encourage them, it is important to leave neglected spots within the productive area, hedgerows, and thickets, and place nest blocks (blocks with holes, or bundles of canes) in the orchard. The use of insecticides must be careful.

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From the point of view of growing technology there are important or possible the following measures:

Planting of compatible cvs. – in self-sterile (fruit species or cultivars), the planted cultivars must produce a high amount of pollen with good vitality, and flowering periods must be identical or overlap at least. In self-fertile cultivars, it is not necessary to combine different cultivars, and single-cultivar orchard blocks are acceptable.
In intensive apple tree orchards, there are used cultivars of botanic apple species (obviously every 10th tree in a row, and several cultivars) – these are not susceptible to diseases, do not need special care, and fruits are not picked, hence do not complicate orchard management.

Mowing of flowering herbs – is recommended in the sod system. Tarragon and other plants flowering at the same period as fruit trees may be competition in pollination if their flowers are more attractive to bees.

Managed pollination – an old technique in which flowers of the species that should be pollinated are macerated in a sugar solution for a few hours. The solution is used then for feeding bees which adapt to the scent of the flowers and search for them as a source of nectar and pollinate them.

There are some pests damaging trees or pathogens infesting fruit species during the period of flowering. When applying pesticides, it is necessary to consider their toxicity to bees. Only those that are safe for bees are permitted. However, the aroma of pesticides caught up the bee's body causes a problem when the bee attempts to enter the beehive after returning from the pollination flight.

Balanced nutrition is important for the proper development of flower buds and their parts including pistils and anthers with sex cells. For better pollen germination and successful oosphere fertilization spraying with Boron fertilizers is recommended. The application is important also when there is a risk of frost because it increases the share of fertilized oospheres and even with frost damage some fruit may survive. The addition of phytohormones to a fertilizer mix or the use of special stimulation agents also helps in these situations.

Protection against frost helps to increase fruit set in risky conditions.

Because the abundance of bees has decreased over the recent period (fewer beekeepers, occurrence of bee pests and diseases), there has emerged a need for a substitution or improvement in their activity to gain a better fruit set. In various countries, there are used following procedures:

Technical pollination – pollen is gathered manually, mechanically, or with pollen traps placed in the beehive entrance where they clear bee legs of pollen baskets when returning from the pollination flight. Collected pollen may be applied by hand, sprayed in suspension, or dusted with machines (in regions of the world with a big concentration of orchards even helicopters are used). Alternatively, pollen may be placed in a pollen bed at the beehive entrance where it is caught up to bees leaving the beehive for the next pollination.

Bee attractants working on a similar principle as pheromones are another invention helping successful pollination. Target fruit trees are sprayed at the beginning of the blossom period to make flowers more attractive for bees.

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Picture 22 Tripol placement in a cherry tree orchard (Koppert, modified by the author)


Picture 23 Botanical apple tree species used as a source of pollen in apple commercial orchards (modified by the author)

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Picture 24 Structures with holes for nesting of natural insect pollinators (modified by the author)

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5 Propagation of fruit plants

Propagation of fruit plants is used for:

- production of planting material (young trees and shrubs) for new orchards and plantations,
- obtaining new genotypes when breeding,
- obtaining a bigger number of plants of a new genotype for further selection within the breeding process,
- getting mother plants as a source of grafts, buds, cuttings, etc. for further propagation.

There are different methods of propagation classified according to which part of the plant is used for propagation. The used propagation method influences not only the practical procedure on its own but necessary ambient (environment, technical equipment, space). The classification is as follows:

1. Sexual (generative) propagation – propagation with seed,
2. Asexual (vegetative propagation) – propagation with the use of vegetative parts of a plant (stem, root, leaves, meristems)
   a. direct (auto-vegetative) – a plant part used for vegetation creates its roots (own-root plants)
   b. indirect (xeno-vegetative) – a part used for propagation (scion) taken from the mother plant is joined (grafted) to another plant (rootstock) which creates its root system

Plant behaviour may differ according to how they were propagated and this fact influences their value for fruit production (see Table 1).

5.1 Generative propagation

Seedlings are mainly used as rootstocks for the more desirable varieties of fruit but their importance in the nursery production of fruit species is decreasing. Seed may be obtained from commercial suppliers, nurserymen, fruit packing houses, or plants grown for seed production on a farm.

A mother (seed) tree must be a heavy cropper, resistant to adverse environmental conditions, pests, and diseases, free of viruses, and must give good offspring, which has good affinity with the cultivars grafted on it. There may be 2 categories of seed trees e.g. certified – the tree that has passed the certification procedure under the supervision of a relevant institution), and registered – the tree with desired properties but has not passed the certification process).

Table 1 Characteristics of plants obtained via generative and vegetative propagation

Generatively propagated	**Vegetatively propagated**
Distinct from a parental plant	Identical to a parental plant
Variable (population of individuals)	Uniform (clone)
Later beginning of productivity	Earlier productivity
Longer life period	Shorter life period
More vigorous (obviously)	Less vigorous (obviously)
Deep rooting – more drought resistant	Variable depth of rooting – obviously less drought-resistant
A big volume of rhizosphere – the higher capacity to absorb nutrients	Smaller capacity to absorb nutrients (obviously)
Transfer of some diseases (virus etc.) is less probable	Transfer of diseases less probable

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Seed is got from mature fruits, from which it must be extracted, washed thoroughly, treated with a fungicide, and dried. Seed obtained from commercial suppliers or nurserymen is often treated already.

It is a good precaution, especially for fruit collected from the ground or coming from a fruit packing house, to sterilize seed surface by soaking seeds in hot water (40 – 50 ºC) for 5 – 30 minutes depending on the seed size, with larger seed requiring longer time. The seeds are then cooled immediately in water, treated with a fungicide, and surface dried. Common (orthodox) seed is dried to 10 – 14% water content (max temp. 40 ºC**),** while re-calcitrant are sensitive to desiccation and must be stored in humid conditions.

The dried seed is tested for biological characteristics and labelled before storing or selling to customers. Seed is packaged in clean, inert packages according to local standards.

The treated seed can be stored in plastic or cloth bags under refrigeration (1 – 7 ºC). Seeds of many temperate zone fruit corps can be stored for 1 – 2 years with little loss of viability. Some seeds (recalcitrant seeds) with a big portion of reserve substances and fleshy tissue are susceptible to drying and must not be dried to the above-mentioned level, and should be stored in moist conditions.

Seed quality attributes are: purity – free of mineral waste (stones, soil, dust) and biological material (stems, fruit rests, seeds of weeds) must be min. 75 – 90%, integrity (free of seeds of other than claimed cultivar or species), germination rate (percentage of seeds able to germinate) determined on germination trays or biochemically, and energy of germination (ability to germinate more-less evenly, within a short period).

The seed value is counted with the use of the following relation:

$$\text{Seed value [\%]} = \frac{\text{purity [\%]} \cdot \text{germination rate [\%]}}{100}$$

Before stratification or planting, dry seeds should be soaked in water for several hours to facilitate germination.

Table 2 Seed yield from 1 t of fruits (Vilkus et al., 1997)

Species	**Seed yield in kg from 1 t of fruits**
Peach – rootstock cultivars	30 – 35
Peach x almond, almond	35 – 40
Apple tree, pear	8 – 10
Apricot	125 – 170
Cherry plum	85 – 100
Spilling, yellow damson	100 – 125
Damson, Saint. Julien, ´Wangenheim´ plum	40 – 60
Tart cherry	50 – 85
Mahaleb cherry	100 – 125
Bird cherry (wild cherry)	85 – 100

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Table 3 Number of seeds in 1 kg of seed (Oberthová et al., 1989, Vilkus et al. 1997)

Species	**Seeds in 1 kg of seed**
Peach	200 – 300
Wild pear	25 000 – 30 000
Wild apple tree	30 000 – 50 000
Apple tree cultivars	20 000 – 30 000
Filbert	150 – 200
Almond	230 – 300
Apricot	700 – 800
Walnut	70 – 100
Wild plum, damson	2 500
Plums and damsons – cvs.	1200 – 2000
Mahaleb cherry	9 000 – 15 000
Wild cherry (bird cherry)	6 000 – 8 000

Seeds of most temperate fruit crops have a dormancy requirement that must be satisfied before they will germinate. The moist, cold storage of seeds to break dormancy is called stratification. The seed should be soaked in water for several hours and treated with a fungicide to prevent from fungi spreading. Seeds are then mixed with moist perlite, sand, peat, or other media and placed into a suitable container such as a seed flat or box. The seed should be covered with substrate and thoroughly watered and drained. Mixing the seed with media in a plastic bag also works well.

The containers with seeds should be kept at 1 – 7 °C for several weeks to months, depending on the seed species. It is important to avoid drying out of substrate with seeds during stratification. The emergence of the root from the seed indicates that the dormancy need has been satisfied and the seeds should be seeded as soon as possible if the soil in open is dry and warm enough (about 5 °C or higher). If the weather is still cold, germination must be retarded with decreasing of temperature to 0 °C and seeding must be delayed until warming.

Seed is sown into rows, beds, or containers (scarce or valuable seed, or sown for a special purpose). Alternatively, the seed may be sown in autumn, and the stratification processes in seeds are going in natural conditions. Weeds emerging during mild winter may be a problem, however.

Table 4 Length of stratification period (Oberthová et al., 1989)

Pome fruit species	**days**	**Stone fruits species**	**days**
Wild apple tree	85 – 90	Tart cherry	150 – 180
Apple tree cvs	80 – 90	Mahaleb cherry	120 – 150
Grey leaved apple tree	70 – 75	Wild cherry	100 – 110
Siberian apple tree	85 – 90	Apricot	95 – 110

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Wild pear	85 – 90	Plums	120 – 150
Ussuri pear	50 – 60		

Table 5 Sowing depth of fruit species seeds (Oberthová et al., 1989)

Species	**Sowing depth in mm**
Peach	50 – 60
Sweet and tart cherry	20 – 25
Pear	10 – 15
Apple tree	10 – 15
Almond	55 – 65
Apricot	40 – 45
Walnut	60 – 75
Plums	30 – 35
Mahaleb cherry	20

Care of seedlings consists of soil cultivation and weeding according to need, watering, and pest and disease control. In the stage of 2 pairs of true leaves cutting the primary root in a depth of 10 – 15 cm under the soil surface is recommended for better root branching.

With some species (peach for example) which grow vigorously budding is possible in the summer after sowing and the trees ready to plant are obtained next year in the same field, with slowly growing rootstocks seedlings may be harvested in the first autumn, sold to customers, or used for grafting-budding.

5.2 Vegetative propagation

There are different methods used for vegetative propagation. Despite the risk of virus diseases transfer with vegetative parts, vegetative propagation plays an essential role in present fruit nursery production.

5.2.1 Direct vegetative propagation methods

5.2.1.1 Plant division

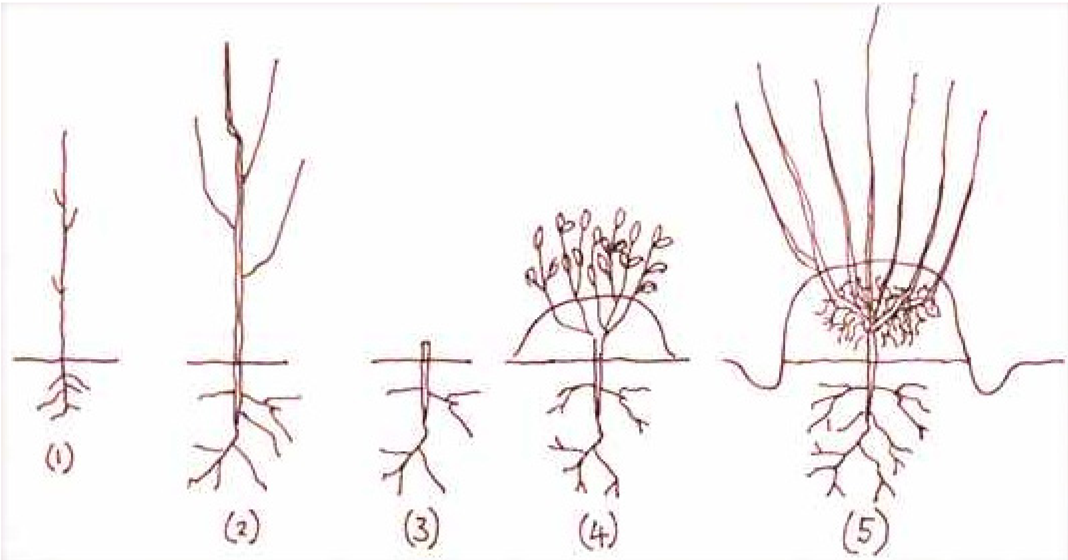
Dividing the parent plant is one of the easiest ways to propagate many berry fruit species. By the time a berry bush is several years old, new plants usually have started to form around the original one. To start as many new little bushes as possible, the best way is to dig up the entire plant and split it with an axe, knife, spade, or pruning shears. Each division should have a good clump of roots on it. If only two or three new plants are needed, it is possible to sever them from their parent with a spade or sharp shovel without greatly disturbing the main plant. The best time to make divisions is in early spring just as new growth starts, or just prior. The brambles (raspberries and blackberries) are especially easy to divide.

Dividing is not a very productive method however and is used only by hobby fruit growers or in special situations.

Some berry fruits — currants, elderberry, and gooseberry for instance — can be started by dividing the large plants. Blueberries can also be divided, but, except for the lowbush kinds, they do not form offsets as easily. One can get the bush fruits to produce large numbers of new plants by cutting back the top of the bush to about 6 inches in height, and piling rich soil or compost over it, completely covering it. New shoots will grow through the soil, and roots will form on their stems. Replace any soil that may wash away in rains, and, the following spring, dig up the entire plant, cut the new plants apart, and transplant them. This process is called the "stooling" of the plant.

5.2.1.2 Stooling (mound layering)

Propagation by stooling in commercial nurseries is usually restricted to rootstocks (apple rootstocks f.e.) though it can work with any own-root trees or shrubs.



Picture 25 Scheme of the stooling propagation method production process – parental plant used for establishing a plantation (1), plants are let to develop for 2 – 3 years to strengthen the root system (2), soil is cultivated and plants irrigated when needed to enhance plant vigour. In the first productive year, plants are cut to the soil (as hard as possible) (3), many shoots are produced from sleeping buds on the plant´s base. When 150 – 200 mm tall, the shoots are mounded with soil, organic substrate, or sawdust (this material is covered with soil then) (4), mounding is repeated 2 – 3 times up to the mound height approx. 25 – 30 cm. Plantation is weeded and irrigated when needed. At the end of the vegetation period, the rooted stools (5) are cut out for further use. (modified by the author)

5.2.1.3 Suckers

Some fruit species (plums, quince, sour cherry, blackberries) produce suckers – shoots growing from plant base and roots, spontaneously or when roots are damaged. Rooted suckers after 1 vegetation period may be dug out for further use.

The method is little productive, and with grafted trees, only a rootstock is produced, with those on their own roots, the cultivar is reproduced. Getting suckers from old plants is risky due to the danger of virus disease transfer.

5.2.1.4 Runners

Runners are plantlets produced on stolons (modified stems) of strawberries. Plants may be produced in plantings used for fruit production, but for commercial production, there are used special plots with plants more widely spaced (allowing free distribution of runners between plants) and flowers removed from the plants (more energy for the production of runners is left). Runners start to emerge on the plant together with flowers that must be pinched out, the runners are distributed over the area with loose soil and irrigated when needed.

Traditional system – plantlets on runners are let to root well spontaneously and dug out from mid of August, then transplanted to productive plantation. Runner plants may be let to

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develop within the mother plantation until the end of the season, and then dug out to be processed as Frigo plants.

Modern system – plantlets with 2 leaves and root primordia are cut from the mother plant runners and planted to a peat substrate under cover. Planting into beds or containers is possible. High air relative humidity and temperature of 22 – 25 °C, together with shading create good conditions for fast rooting (plants are fully rooted within a few weeks). Harvesting of plantlets may continue until the second half of summer. With this system, productivity is much higher than with the traditional one. Plants may be used for direct planting to productive plantations or processed as Frigo plants (below).

Frigo plants – well-developed and rooted runner plants are dug out from the soil when entering dormancy at the end of the season (end of October – mid of November). Plant roots are cleaned from the substrate, only 2 central leaves are left, blades of others are removed and plants in bunches are placed in plastic bags or containers and stored at -1 °C and high relative humidity until planting (up to almost the next Frigo cycle). Frigo plants may be planted whenever conditions allow it (in the open, under cover), flower about a month from planting, and fruits may be harvested after another month.

Picture 26 Strawberry runner plants prior to being inserted into a rooting substrate (Paulen)

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Picture 27 Rooting runner plants in pots (Paulen)


Picture 28 Frigo plants ready for planting (Żurawicz, 2005)

5.2.1.5 Layering

Layering works well with gooseberries, currants, filberts (hazelnut), quince, black raspberries, elderberries, and certain other fruits, all of which root within a few months. It is likely to take at least a year in plums, peaches, apples, blueberries, and cherries to form good roots, and in pears, walnut, and hazelnut it may take several years (hence it is not used commercially in those species). For the method, a tree or bush with branches close to the ground is a basic condition.

Procedure: one or more shoots are bent to the loosened soil beneath, and a section of the middle part of the shoot is buried under the soil. If necessary, the buried shoot is fixed with

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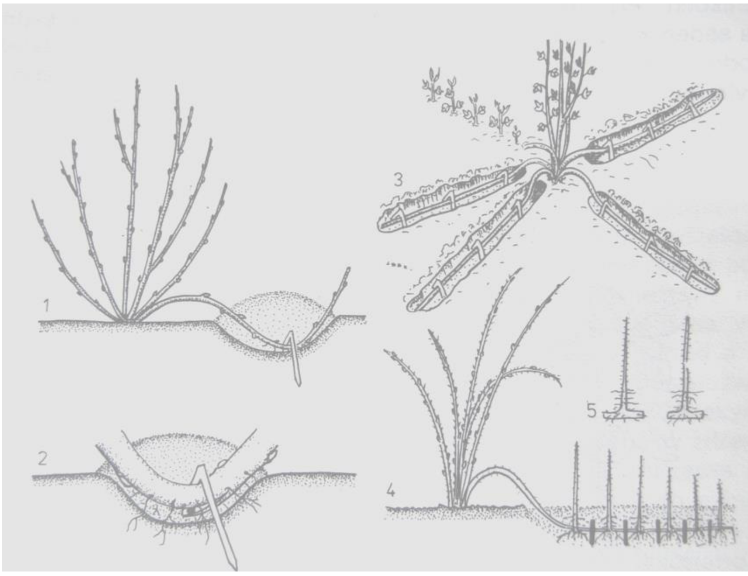
a rock or hook in place. The end of the shoot, bulked out the soil, is staked to point it straight up. Roots will eventually form on the section of the shoot that was buried. When enough roots have developed to support the plant, the daughter plant may be cut from its parent, but it is left to grow in the same spot so it can develop a strong root system, In autumn or the next spring new plants are dug out and planted in a permanent position. Another variation is to just bury the tip, as with blackberries and tayberries (the process occurs naturally also), from which a new plant will root and grow (tip layering). Rooting can be hastened by scraping a bit of bark from the bottom part of the shoot that is to be buried in the soil and treating the wound with a rooting compound (artificial auxins). The first procedure is simple layering.

Shoots of the plant may be distributed around the plant radially (as sun rays) and fixed on the bottoms of the dug furrows horizontally. After emerging of shoots the furrows are backfilled with soil or peat substrate, and individual shoots may root until the end of the season – ray layering (more productive than simple layering, but daughter plants are smaller).

Serpent (compound) layering is possible in plants with long flexible shoots whose parts are alternately serpent-like bent and buried in soil and left above the soil, thus producing several strong plants from each shoot.

Air layering is used in countries with warm climates and in woody species that do not root easily. The selected branch is scrapped at its bottom portion, and the damaged part is wrapped in a plastic bag filled with damp peat moss or similar material, and left until roots emerge. The rooted branch is then separated from the mother plant.



Picture 29 Layering – simple (1, 2), ray (3), young plants separation in ray layering (4, 5) (Oberthová et al., 1989)

5.2.1.6 Cuttings

Though exploitation of this method differs among countries and fruit species, it has many advantages and is possible in most fruit species' rootstocks as well as cultivars. Stem cuttings are most commonly used although root cuttings work well with some species.

Cuttings may be used for the propagation of currants, blackberry, blueberry, mulberry, Actinidia, elderberry, honeysuckle, apple rose, and some rootstocks of pome and stone fruit species.

Softwood stem cuttings can be taken at the end of spring (May, June) from new growth. Terminal portions of shoots should not be used unless the growth has matured and somewhat hardened. The cuttings can be cut 10 – 15 cm long and the leaves removed from the lower third to half of each cutting. Rooting hormones may be used to hasten the rooting of cuttings. Cuttings

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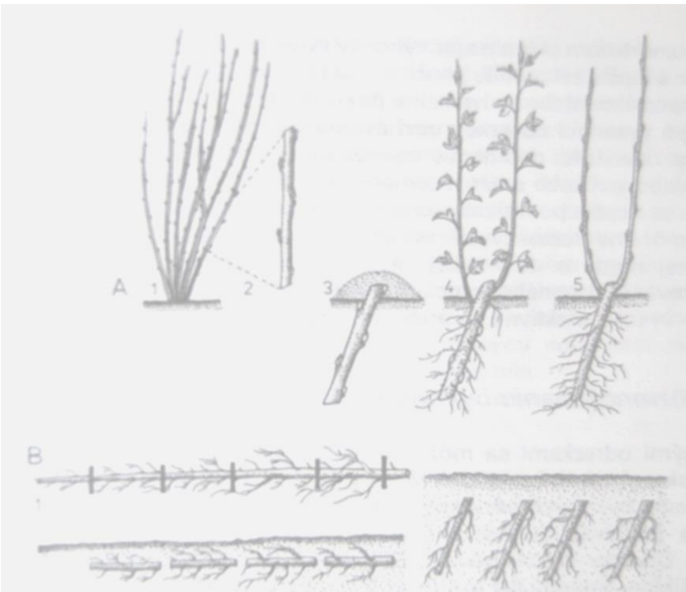
can be inserted into a medium containing a 1:1 mixture of perlite and peat or other suitable materials such as vermiculite or sand. The medium should be well-drained and sterile. Intermittent misting should be used to reach 100% relative humidity and to minimize water loss from the cuttings until rooting occurs. The optimum temperature is between 23 and 27 ºC Mist should be applied just long enough and frequently enough to prevent the leaves from wilting. After rooting, the cuttings can be hardened off by reducing the misting interval, ventilation, or by placing them in pots in a shady location for several weeks.

Semi-hardwood cuttings are taken in the second half of summer when shoots are partly matured and inserted in the substrate under cover. The method is not typical for fruit woods propagation and is used mainly in decorative woods.

Hardwood stem cuttings of some plants can be successfully rooted. Dormant wood 6 – 20 mm in diameter is cut into lengths of 15 – 30 cm. Better rooting will occur if the basal cut is made just below a node. The prepared cuttings can be treated with a rooting hormone, tied in bundles of convenient size, and placed upside down in a callusing box. The bundles should be covered with moist, sterile peat moss or other suitable callusing media. The cuttings should be planted out after they have produced the callus (formation of a pad of yellowish-white tissue at the base of the cutting) but before many roots are produced. The entire cutting should be buried so that only the top bud is exposed. Alternatively (with currants f.e.) the cuttings are inserted into thoroughly prepared soil in open immediately after preparation, and callusing goes in the soil when temperatures are suitable (the next spring). In some species (black mulberry etc.) old-wood cuttings proved well – older branches (up to 10 cm diameter) are cut to 20 – 25 cm chunks during the dormant period, 1-year-old shoots are removed, and cuttings are buried completely in a peat substrate, sawdust or another substrate in containers in a glasshouse, where they are kept until rooted at warm temperature (20 – 24 ºC), possibly with bottom heat.

Root cuttings can be made by digging the plant to be a source of cuttings and separating the roots that are about the diameter of a pencil. These can be cut into lengths of 5 – 15 cm, tied in bundles, and stored in damp burlap or polyethylene bags until planting out. They can be planted in a propagation bed during the shoot formation period. Use of root cuttings is possible in plants with adventive buds on roots e.g. blackberry, raspberry, quince, and sour cherry.



Picture 30 Propagation by cuttings – stem hardwood cuttings (A), root cuttings (B) (Oberthová et al. 1989)

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5.2.1.7 Tissue culture (*in-vitro* propagation)

Plant tissue culture is no longer a laboratory experiment but has become a standard method of propagation for commercial nursery production, and the cloning of plants in huge numbers has become routine. Some plants frequently propagated in this manner are blueberry, raspberry, strawberry, and dwarf fruit tree rootstocks used for grafting. The tissue culture of woody plants is very demanding and requires expensive equipment and skill.

Simply stated, technicians, working in sterile conditions, place a small piece of a plant, usually a growing bud or piece of plant tissue, in a special solution (medium) in a test tube (jar) where it begins to grow. Then, they divide it and put the divisions into larger jars with a different nutritive solution where the divisions develop stems and roots. Temperature, pH, and humidity also must be carefully controlled. Once the new plants form roots and shoots, they must be gradually acclimated over stages to the real world (*in-vivo*) outside the jars.

The advantages of tissue culture are many. Huge numbers of plants can be started without having large amounts of stock plants on hand since the culture can be stored and plants started as needed. This is one way lots of new cultivars are made available in a short time. Each plant is completely free from all diseases, including the viruses that are so difficult to control, so everything produced can be certified as disease-free. For this purpose, few plants obtained via *in-vitro* culture are kept for longer period under higher temperature to eradicate possibly present viruses. The treatment is known as thermotherapy and the obtained plants are used as source material for the production of VF (virus-free) plants. The source plants must be true to the cultivar, and after the thermotherapy, they are grown in technical isolators (mesh houses).

5.2.2 Indirect vegetative propagation

The most common method of propagating fruit trees, suitable for nearly all species, is grafting onto rootstocks. This, in essence, involves physically joining part of a shoot of a cultivar (scion) onto the roots of a different but closely related species or cultivar (rootstock), so that the two parts grow together as one plant. The process of joining the two varieties must ensure maximum contact between the cambium (the layer just below the bark) of each so that they grow together successfully. Grafting is a preferred method because it not only propagates a new plant of the desired hybrid cultivar, but it usually also confers extra advantages as a result of the characteristics of the rootstocks (or stocks), which are selected for characteristics such as their vigour, hardiness, and soil tolerance, as well as compatibility with the desired variety that will form the aerial part of the plant (called the scion).

There are 3 main procedures of indirect vegetative propagation:

- budding,
- grafting,
- ablactation.

Budding involves the use of a scion with only a single bud attached to a piece of bark. It may or may not include a thin sliver of wood under the bark. Budding is the most commonly used technique for propagating new plants, but it is sometimes used to top-work existing trees to a new cultivar. It is relatively simple and easy to do. Budding is mostly done from the end of spring until the end of August (possibly to mid-September in warmer regions and chip-budding technique).

Grafting involves the use of a scion having 2 or more buds. There are numerous types of grafts including whip, side-veneer, cleft, bark, inarch grafting, and others. In hobby gardens grafting is commonly used to repair or top-work existing trees and to produce trees of new cultivars. Grafting of fruit trees is mostly done in the dormant period or just before budburst (in open), less often in the second half of summer, when growth has ceased. Grafting done in rooms during winter with rootstocks dug out and prepared grafts and grafted plants placed in storage until planting in spring refers to bench grafting. It helps to organize work in nursey more effectively (using dull winter period) and gives good results.

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Ablactation (grafting on approach) is a method of grafting, wherein the scion of one tree, being united for some time to the stock of another (with cuts made on united parts the way that cambiums are in close contact) both having their own root system. The scion is after growing together cut off and, as it were, weaned from its mother tree. The technique is quite ancient, and non-productive, hence it is not suitable for commercial use.

Picture 31 Whip and tongue grafting (Paulen)

Picture 32 Bench-grafted rootstocks (Paulen)

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Picture 33 Apple tree occulates in nursery (Paulen)


Picture 34 Fruit tree nursery (Paulen)

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6 Growth and development of fruit plants

Growth and development are key characteristics (attributes) of living organisms. Growth is an irreversible increase of phytomass connected to the activity of protoplasm. Hence, its nature is the change of quantity.

The overall growth of organisms is the result of complex metabolic processes and besides the matter produced via photosynthesis, it requires an energy supply. The energy is released when the prepared organic compounds are dissimilated.

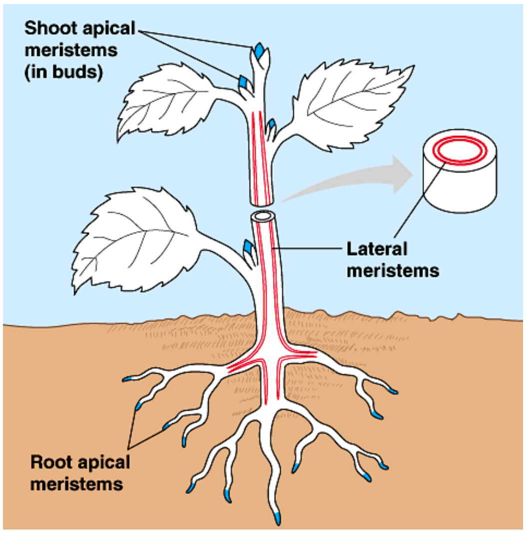
The growth of individual plant parts is realised due to meristematic activity (primary and secondary meristems) that is localised at different places within the plant. Primary meristems are vital for increasing plant size, and secondary meristems are essential for producing specialised tissues. Both are indeterminate (may produce plants of different sizes). According to their localisation meristems are classified as:

- apical and sub-apical (elongation of stems and roots)
- lateral (thickening of stems and roots))

Meristems are localised in shoot and root tips (apical meristems), and in some situations, the apical meristem is transformed into a floral meristem which produces floral parts. Lateral meristems are found in older parts of stems and roots where they are responsible for the secondary thickening of those organs. Besides that, there are found meristems that produce cells for a limited period and form organs of predictable size and form. Unlike previous meristems, the cells of these meristems are partially differentiated. They are classified as "quasi-meristems" and are important for leaf and fruit development.

Apical meristems may differentiate into three kinds of primary meristems:

- protoderm – lies around the outside of the stem and develops into the epidermis,
- procambium – lies just inside of the protoderm and develops into the primary xylem and primary phloem. It also produces the vascular cambium, and cork cambium, secondary meristems. The cork cambium further differentiates into the phelloderm (to the inside) and the phellem, or cork (to the outside). All three of these layers (cork cambium, phellem, and phelloderm) constitute the periderm. In roots, the procambium can also give rise to the pericycle, which produces lateral roots,
- ground meristem – develops into the cortex and the pith.



Picture 35 Localisation of meristems in plants (modified by the author)

There are two secondary meristems in fruit plants which are also called lateral meristems because they surround the established stem and cause a lateral increase in its volume:

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- vascular cambium (cambium) – produces secondary xylem and secondary phloem. This is a process that may continue throughout the life of the plant. This does not occur in plants that do not go through secondary growth (herbaceous plants, palms),
- cork cambium (phellogen) – gives rise to the periderm, which replaces the epidermis.

Growth is performed due to an increase of cell number via cell division and consequent increase of their volume.

Besides growth – a quantitative process also the processes of new tissues, organs creation (qualitative changes) occur that are known as development. Growth and development are tightly coupled obviously.

New cells produced due to meristematic activity are differentiated (to fulfil different tasks) and different tissues are formed. Single growth (not coupled with development) occurs for example when propagating plants *in vitro* wherein in certain conditions (on cultivating medium and influenced with phytohormones) callus – a mass of unorganized parenchyma cells is formed. A similar situation is observed shortly after a plant is damaged – a callus formation is the first stage of a wound healing process.

During its life cycle, the plant is characterized by growth and development (ontogenesis). While for the propagation of fruit plants different methods are used – generative and vegetative, the course and dynamics of these processes may differ in plants of various categories.

6.1 Development in generatively propagated plants

In plants of this category, the life cycle starts with the fertilisation of egg cells in the pistil of a flower. From that moment the plant passes several phases.

6.1.1 Embryonal phase

The basic process during this phase is the development of an embryo in a fruit. Conditions for the development of viable embryos are allowing the genesis of a new plant as a continuation of the species. The viable embryo is important for the developing fruit also – fruit with imperfectly fertilized egg cells drops soon after blossom (so-called physiological fruit drop), and only the fruits with the perspective of full-featured development stay on the plant. In the fruits of the earliest cultivars, the period from flowering until harvest is too short to allow full development of the embryo and in natural conditions, such plants cannot be propagated by seed.

6.1.2 Juvenile phase

This phase lasts from seed germination until the formation of the first generative organs on the plant. The plant produced from seed differs in some traits from the mother plant obviously cause its genetic material came from two parents.

Juvenile plants also differ from adult ones with the following morphologic and anatomic features:

- no generative organs are formed, and energy and material resources are used only for vegetative processes therefore plant grows more vigorously compared to mature plants,
- leaves are smaller, columnar parenchyma in leaves is less developed, and heterophylly occurs quite often (leaf shape different from the mature plant) in an apple tree, pear, walnut, currant, gooseberry etc.,
- smaller buds, wide angles of branching,
- the presence of thorny shoots in some species (plum, apricot, apple tree, pear),
- big share of xylem compared to phloem,
- the weak ability to stock reserve substances,

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- forming of thin temporary shoots which drop together with leaves at the end of the season (peach),

- forming adventive roots is easy.

The juvenile phase lasts different periods – peach tree and berry fruit species 2 to 4 years, apricot 4 to 6 years, apple tree 3 to 9 years, pear 7 to 14 years, walnut, chestnut, and service tree 10 to 20 years. The period may be somewhat shortened with agrotechnical measures influencing phytohormonal regulation of the processes in the plant.

6.1.3 Adult phase

The phase starts when generative organs have been formed and is manifested with changes in the plant anatomy and morphology. Individual parts of the plant enter the period in which they can form generative organs at different times. The number of the formed generative organs is conditioned by many factors therefore also in this phase the periods when no fruits are formed can occur.

Similarly to the previous phase, the signs of plant ageing are manifested e.g. decreasing the vigour of vegetative organs, dying of some plant parts, increasing share of generative parts (more flowers and fruits a produced), inclination to yield alternation, increasing susceptibility to adverse environmental factors (diseases, pests, low temperatures etc.) and decreasing regeneration ability. These processes are influenced also by root/above-ground part interaction. Since plant integrity is often disturbed with pruning, rejuvenation is also manifested during the plant´s life.

Ageing and rejuvenation processes occur in plants during the whole life period and cannot be separated. Their intensity is regulated by phytohormones. Due to that ageing of different plant parts is uneven. Differences in ageing are affected by the following factors:

- species – development of stone fruit species is faster than that of long-living nut species, and stone fruit species are ageing more quickly,

- cultivar – productive cvs. are ageing more quickly and have shorter life period cause the plants are exhausted by yielding,

- branch category and its position within the crown – lateral branchlets, bent and weeping branches are ageing most quickly while terminal shoots and branches in an upper portion of the crown are vigorous and age slowly,

- nutrition and soil management – a high supply of Nitrogen slows ageing, a high supply of Phosphorus enhances the fruiting of young trees, water availability – drought stress enhances ageing, soil management – sod system requires more water and nitrogen and causes lower vigour,

- pruning – dormant pruning invigorates trees, mainly hard pruning causes a regeneration wave which is a sign of rejuvenation while summer pruning may decrease vigour and enhance productivity,

- health – in general, the plants that are neglected, diseased or damaged by pests are ageing more quickly, however, the disturbed plant´s balance or death of some part may cause local rejuvenation (formation of water shoots).

6.1.4 Senescence phase

The senescence phase is manifested with a remarkable vigour decrease and an increased rate of branch dieback. These processes are often accompanied by spontaneous local rejuvenation. However, the newly produced parts are ageing quickly and the phase is terminated by the plant´s death.

Picture 36 Senescence phase is not typical for intensive fruit orchards (modified by the author)

6.2 Development in vegetatively propagated fruit plants

The plants propagated from vegetative parts of adult mother plants remain in the adult phase and theoretically, they may produce generative organs already in the year of propagation. However, the productive period is preceded by visible rejuvenation manifested by vigorous growth, and the creation of generative organs is delayed obviously. Due to it, even the ancient (hundreds of years old) cultivars may be maintained in a vivacious state, with repeated rejuvenation after each propagation because the senescent plants must be replaced with young ones. The new plants are produced vegetatively, and the process is repeated. After several generations of vegetatively propagated plants, a decrease in the vitality and productivity of the cultivar is observed. This is obviously due to infestation with viruses, mycoplasmas or other pathogens that are transferred via vegetative parts. Also, mutations may occur leading to genotype changes and the cultivar is not uniform anymore despite the vegetative propagation.

During the life cycle of vegetatively propagated plants, from the time of propagation until death, different periods occur which are called age periods. Based on the relation between growth, yielding and dying, Armenian fruit scientist, P.G. Shitt divided the life cycle of vegetatively propagated woody fruit plants into 9 age periods. Onset and length of individual periods may be different within the fruit species, and they are influenced by species, cultivar, rootstock, environmental conditions, nutrition, growing technology, pruning, and training of the tree – the effects are similar to those in generatively propagated plants. The value of age periods for the grower is different. In commercial conditions, only the periods with potential profitability are exploited. Age periods are named according to the role of individual processes (growth, yielding, drying = ageing) within a given period. The dominating process is the first and the least manifested is the last within the name of a period. Age periods are as follows:

6.2.1 Vegetative growth period

The period lasts from propagation until the first flowers and fruit. The length of the period depends on species and cultivar, rootstock and is much influenced by environmental conditions and care given to the tree. It may last up to 10 – 12 years.

Manifestation:

- vigorous growth of roots and shoots,
- trunk, scaffold branches, and main roots are being formed, 1-year growth is long,
- a quick increase of the crown volume, the stronger is growth the later is fruiting onset.

Growing measures:

Formative pruning, minimum or no fertilization, irrigation according to the plant requirements, and soil management aimed at avoiding competition from grass and weed (fallowing or soil mulching is preferred). Sometimes growing of intercrops is allowed, but a necessary distance from trees should be kept.

6.2.2 Growth and yielding period

The period lasts from the first fruits until economically important yields.

Manifestation:

- vigorous growth of terminal shoots,
- formation of fruiting garniture on branches and gradually increased productivity, yielding is regular (good return bloom),
- wide growth/generative bud ratio that is more leaves per 1 fruit assuring its proper nutrition, flowers are well developed, fruits are big.

Growing measures:

Formative pruning is finished, and proper soil management with possible sod or soil greening can be established at the end of the period. Launching of regular fertilization programme.

6.2.3 Yielding and growth period

The period lasts from economically important yields until the plant's highest productivity.

Manifestation:

- decreasing vigour of shoots, decreasing rate of branches prolongation,
- intensive formation of fruiting wood,
- a slow rate of crown volume increase,
- more-less balanced growth/vegetative organ ratio,
- first signs of yield alternation in the susceptible cultivars,
- beginning of garniture drying – the shaded laterals, starting from the bottom and inner portions of the crown.

Growing measures:

Orchard management is oriented on keeping the length of shoots (vigour) with proper fertilization, soil management, irrigation as needed, pest and disease control and avoiding yield alternation (fruit set regulation), established pruning oriented on branch thinning and removal of aged garniture.

6.2.4 Yielding period

Period of the highest productivity in given environmental and technological conditions.

Manifestation:

- terminal shoots are short,
- formation of generative organs prevails over vegetative ones,
- a big number of fruits causes their lower quality and exhausts the tree,
- yield alternation,
- increased susceptibility to frosts, diseases, and adverse environmental conditions,
- dieback of laterals advances from the centre of the crown towards its periphery.

Growing measures:

Fertilization considering growth and yielding is important, and irrigation as needed, thinning cuts and detailed rejuvenation pruning, and fruit thinning. In intensive orchards, it is mostly the last period of the tree life and when signs of ageing – a decrease in fruit quality and production process effectiveness are observed, and the orchard is discarded.

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6.2.5 Yielding and drying period

The period starts with the decrease of yields and lasts until the beginning of water shoots forming on the top of naturally bent branches.

Manifestation:

- minimum growth,
- massive dying of garniture all over the crown volume, even in its periphery, dying of higher-order branches,
- yields are still satisfactory though less regular and fruit quality decreases.

Growing measures:

Radical rejuvenation pruning and soil and plant management to increase the vigour of the tree (fertilization, protection of leaf area and helping its function with foliar fertilization for example).

6.2.6 Drying, yielding and growth period

The period lasts from the beginning of water shoots forming on naturally bent branches to the onset of productivity of branches developed from water shoots.

Manifestation:

- dieback of garniture and higher-order branches (also deep into the crown),
- on water shoots arising from the bent branches and in airy parts of the crown fruiting garniture is being formed,
- yield decrease.

Growing measures:

Dying of bent and weeping branches may be solved with radical rejuvenation pruning after which the formed water shoots are used to build new branches and reconstruct the crown. During the recovery, there may occur an unproductive period until the time when new fruiting wood is formed. Fertilization and proper care (early summer pruning, pest and disease control, protection of leaf area) are necessary to recover the tree condition in the shortest possible period.

6.2.7 Drying, growth and yielding period

The period lasting from the beginning of the productivity of branches developed from watershoots to the prevailing share of their productivity within the total productivity of the tree. Manifestation:

- dying of scaffold branches,
- yielding is moving to newly formed branches,
- intensive production of water shoots.

The tree is not prospective from the aspect of the production of high-quality fruit.

6.2.8 Drying and growth period

In this period the crown, and trunk also die gradually, and suckers emerge at the base of the trunk, and around the tree, arising from the roots. Almost no fruits are produced.

6.2.9 Growth period

After the above-ground part has died, new above-ground parts are formed from suckers. New individuals with their own root systems are created and may continue with a new developmental cycle.

This developmental pattern is typical for fruit trees, mainly those grown without regular care – pruning, fertilization, irrigation, and thorough soil management. In intensive fruit orchards, the development dynamics are changed – the growing technology is oriented on the early onset of the productive period, which contributes to the general acceleration of development, individual age periods are shortened, sometimes overlapping each other and trees are allowed to live only until they are effective and produce fruit with desired quality (until the 4th age period).

6.3 Acceleration of fruiting period of fruit woods

Acceleration of fruiting period onset is a typical attribute of intensive fruit production. Early onset of productivity may mean increased effectiveness while the cost of technology is the same or only slightly increased compared to the orchard with a delayed fruiting period. To gain acceleration of fruiting the natural patterns of growth, yielding and ageing are respected and exploited. It is possible to use different methods and their combinations.

6.3.1 Selection of cultivars

The selection of cultivar in this aspect is based on understanding growth and yielding relation. Moderately growing cultivars are mostly typical with earlier fruiting period onset than vigorous cultivars and their productivity is more regular. The remarkable effect may be gained particularly when selecting dwarfed cultivars of those species which naturally start to produce late.

Specific growth habits are found in fruit species e.g. apple spur types, columnar cultivars, compact sweet cherry cvs., dwarfed or columnar cvs. of the other species which are typical with low growth intensity, small crowns, early onset of the fruiting period but short life period.

6.3.2 Selection of rootstocks and the height of grafting

It is based on understanding rootstock effects on the scion part including the effect of its portion size within the plant on plant growth and yield characteristics. Currently, trees in intensive orchards which are typical with an early start of yielding are grafted on vegetatively propagated dwarfing rootstocks. Such trees have crowns 50 – 80% smaller than trees on seedling rootstock (vigorously growing). This fact enables dense spacing and effective space exploitation. The trees are oriented on the early formation of fruiting branches. For weakly growing cultivars, dwarfing rootstocks are acceptable only in the best conditions and the densest spacing is used in such cases.

The rootstock effect is increasing with its higher share within a plant. To reach it, the most intensive apple trees are grafted at 0,3 – 0,4 m height.

The start of yielding is very late when using vigorous rootstocks, and the trees have big crowns. The yielding of those trees tends to be irregular and the life period is longer.

Dwarfing rootstocks are currently used in many fruit crops – apple, pear, sweet and tart cherry, and plum but also in some others.

6.3.3 Growing measures

Within a complex of growing measures, a farmer creates conditions for the optimum photosynthetic activity in leaves and for effective exploitation of assimilates (lower consumption of assimilates by vegetative plant's parts). Proper light conditions are important and can be influenced by tree spacing, tree form, crown structure, etc.

Pruning and training of trees may influence the start of the fruiting period remarkably. Fruiting can be accelerated with branch bending to a horizontal or weeping position, summer pruning and shoot pinching. Girdling and strangling performed at the branch base (in pome fruit species) help earlier start of fruiting. Those treatments limit the flow of assimilates to roots which increases their concentration in the above-ground part in favour of flower bud differentiation. Also, the cuts made to the trunk (up to ½ – 2/3 of the diameter) and root pruning are effective in decreasing growth intensity and enhancing flower bud differentiation.

Maintaining the tree's good condition and active leaf area (proper pest and disease control) is important for tree productivity. Adequate doses of nitrogen ensure normal growth and do not delay fruiting while plenty of nitrogen has a negative influence. A balanced nutrition with macro and trace elements influences a fruiting period onset positively.

The use of phytohormones is based on understanding their role in the plant. The availability of products with phytohormones on the market depends on their registration in a given country. There have been studied effects of different substances e.g. TIBA, paclobutrazol, CCC etc. The effect of phytohormones is ambiguous – it is influenced by species, cultivar, and physiological plant status, therefore they are not recommended for general use.

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7 Environmental requirements of fruit species

Environmental factors influence plants in a complex, in mutual interactions the effect of individual factors may be enhanced or weakened. The effects differ also regarding a life period, root system robustness, plant condition, species, cultivar, the plant organ which is affected (older branches, shoots, flower, or vegetative buds), phenophase, etc. Ecological factors may be classified according to different aspects as follows:

According to their role in a plant´s life:

1. Necessary (indispensable) – basic conditions of plant existence (Oxygen, CO_2, heat, light, water, nutrients), can´t be substituted with any other ecological factor,
2. Dispensable – factors not necessary but their presence influences the state and condition of plants – air movement, landscape topography etc.

According to their origin:

1. Spatial (practically uncontrollable by man) – light (solar radiation), air movement, etc.,
2. Terrestrial (partially under the control of man) – soil, plant activity, anthropogenic effect.

According to their character:

1. Meteorological – light (solar radiation), heat, air and its movement, relative air humidity, precipitation,
2. Soil (edaphic) – physical and chemical properties of soil (topsoil and subsoil), parental substrate, soil microbial community,
3. Topographic – altitude, latitude, longitude, relief, exposition, and inclination of slope (on steep relief),
4. Biological – the influence of neighbouring plants and animals, anthropogenic influence.

7.1 Meteorological factors

7.1.1 Sunlight

Sunlight influences:

- the intensity of photosynthesis (photosynthetically active radiation – PAR, only 1 to 3% of PAR is exploited by plants). Sunlight is classified as direct and diffused (reflected from media interfaces, leaves, soil, water surface, going through clouds, etc. Diffused light contains 50 – 60% of yellow-red spectral components usable in photosynthesis while direct light only 37%.
- growth and development of plants,
- plant morphology (lack of light causes longer internodes, thin shoots, small and narrow leaf blades, smaller buds, less intense branching, crowns are more upright and narrower),
- flower bud differentiation (insufficient light intensity disturbs differentiation, in some strawberry cultivars differentiation occurs only under short-day conditions),
- fruit colouring (intense light during ripening causes more intense fruit colour, fruits inside crown, shaded ones lack blush), lack of light causes lower photosynthetic productivity and smaller fruits. The absence of light causes etiolation which is used in stooling – propagation, and in bagging fruits to obtain a special colour and quality),
- assimilates accumulation, entering a dormancy – changes of the light spectrum together with decreasing daylight period and temperature,
- excess of light causes a temperature increase in the irradiated tissues, leaf scorching, and sunscald of fruits.

Light intensity may be modified depending on terrain configuration – shading may be caused by surrounding hills, valley bottoms are shaded part of a day depending on their orientation, and different elements in the landscape (tall trees, buildings, trees within orchard). South slopes are irradiated most while those facing north obtain the least sunlight.

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Best irradiation is found on top parts of hills and broad plains. Light intensity decreases with decreasing altitude, increasing relative air humidity, and air pollution. The position of the leaf within the crown is important (sufficient light intensity for all leaves is found only in small or flat crowns). The proximity of big water surfaces reflecting light increases light intensity. Row direction also influences light conditions – north-south orientation allows the best light saturation. Soil management influences albedo – a reflection of light from the soil. Pale,

Species order according to light requirements (from the most demanding to humble species) – walnut, almond, peach, apricot, early sweet cherry cultivars, late pear, apple and plum cultivars, early pear, apple and plum cultivars, raspberries, blackberries, black currant, red and white currants, strawberries, gooseberry, sour cherry, and black elderberry which withstands partial shading.

Optimum light conditions and their exploitation may be gained with:

- careful planting site selection,
- proper planting scheme (spacing),
- suitable crown form (the ideal situation is if leaves in the top portion of the crown may use the light reflected from lower leaves), mainly small crowns opened to light penetration.

Picture 37 Sunburn in walnut (Paulen)

7.1.2 Heat

Heat influences transpiration, water, and nutrients intake from the soil determines the dynamics of phenophases and growth speed, influences the occurrence of pests and diseases, fruit quality and storability (in winter cultivars of apple and pear)

There are different temperature categories used to indicate the temperature requirements of plant, e.g. optimum temperature – the temperature under which a given process is the fastest or most perfect. Temperature optimum is different for different species and processes also, as are minimum and maximum temperatures, and mean annual temperatures for individual species.

Temperature regime is varying regarding:

- altitude (temperature gradient 0,8 ^{o}C of mean annual temperature per 100 m in CE conditions),
- slope exposure (to directions) and inclination (steepness) – in the northern hemisphere, south-facing slopes are warmer and evaporation there is higher, east and west have similar temperatures but west slopes are mostly more humid, the soil is freezing less deeply, and dew is drying out later, northern slopes are the coldest and most humid,

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- terrain configuration (bottoms of valleys and places above the barriers located on slopes are the spots where cold air accumulates under radiation conditions – classified as frost pockets, the lowest temperature is found on soil level up to 0,2 – 0,5 m above soil surface under calm atmosphere, upland platforms are less prone to late frosts and strong radial frosts, and are very good for fruit growing if sheltered from strong winds with higher hills,
- vicinal (proximity) relations (neighbouring rocky massifs accumulating heat and releasing consequently, big ponds, sea, rivers with high thermal capacity, extensive forests, meadows, urban areas)
- soil cover/soil mulching inhibits a heat exchange between soil and atmosphere, snow protects soil from temperature decrease f. e. a 50 mm snow layer keeps soil temperature by 5 – 14 ºC higher than the air temperature, and loose soil also insulates.

For plants, there are important dynamics of temperatures during the whole year. Low and less often high temperatures may endanger fruit plants for example late frosts in early phases of vegetation, high temperatures during fruit development, or high temperatures stimulating budburst at the end of winter.

Order of temperate zone species according to their heat requirements: almond, peach, apricot, walnut, quince, sweet cherry, plum, pear, sour cherry, blackberries, raspberries, currants, gooseberry, apple tree. critical temperatures for fruit species at different phenophases and phases are the following:

- above-ground parts at endo-dormant phase – apple tree to -35 ºC (some cvs. even lower), pear, plums, cherries -25 to -30 ºC, almond, peach, and walnut -20 to -25 ºC, apricot to -25 ºC, Actinidia to -16 ºC, currants, gooseberry and raspberry lower than -30 ºC.
- roots – apple tree -7 to -15,5 ºC, pear -9 to -11 ºC, peach -10 to -14,5 ºC, currants -15,5 ºC, gooseberry -18 ºC
- opening flowers – pome fruits, stone fruits -4 ºC, almond, apricot -2 ºC, peach -3 ºC, others -2 ºC.
- stigmas of opened flowers -0,5 to -1,5 ºC
- flowers in blossom period – pome fruits -2,2 ºC, peach -2,2 ºC
- young fruitlets – apple tree -1,7 ºC, pear, cherry, plums, peach -1,1, apricot -0,6 ºC.

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Picture 38 Frost damage during bud burst period results in irregular bud bursting in mulberry (Paulen)

Picture 39 Impact of late frost occurred after flowering in sweet cherry

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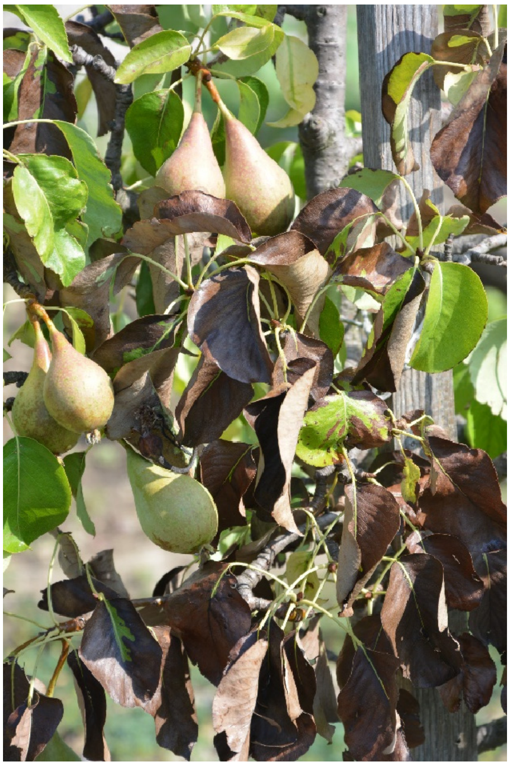
Picture 40 Manifestation of late frost damage in apple fruits (Paulen)



Picture 41 Leaves of pear tree burned due to excessive heat (Paulen)

7.1.3 Air and its movement

Air influences mainly through the contents of oxygen and CO_2 that are necessary for basic processes in plants. The atmosphere layer close to the soil is enriched with CO_2 released from the soil.

Some gases produced by industry, agriculture, other human activities, and natural processes may have adverse effects on plants – F, Cl, SO_2, NO_x, etc. Raspberry (*Rubus idaeus*), service tree (*Sorbus* sp.), and hazelnut (*Corylus* sp.) are the most susceptible species. Pear and apple trees show lower infestation with scab in regions with slightly increased concentrations of SO_2 in the air. Also, solid emissions in the air (dust) have adverse effects on plants. Plants with glossy leaves (walnut, mulberry, sour cherry) are more resistant to dust. Higher content of ozone damages plants. Among susceptible there are – *Armeniaca vulgaris*, *Cornus mas*, *Hippophae rhamnoides*, *Juglans regia*, *Malus* sp., *Morus* sp., *Cerasus avium*, *Prunus persica*, *Rosa* sp., *Rubus* sp., *Sambucus nigra*, and *Sorbus domestica*.

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Air humidity influences plant transpiration. Higher air humidity is found in cool regions, forestal landscapes, and around ponds and rivers. Sprinkler irrigation increases air humidity also. Apple tree is among the most susceptible fruit species to low air humidity. When the temperature decreases air humidity increases, and at the temperature of dew point water steam changes to liquid – dew. Wet leaves create conditions for the spreading of fungal diseases. Air humidity influences leaf morphology – in dry conditions, smaller and more tough leaves are developed, hairy in some species, with thicker cuticle.

Low air relative humidity may cause wilting, yield decrease, excessive June drop, premature fruit drop, and affects flower bud initiation and differentiation negatively. Air humidity is influenced by precipitation, soil moisture, evaporation (higher close to forests, meadows, water surfaces), period of the year, time of day (in summer on hot days air humidity may fall under 30%, in other periods of year 50 – 70%, and in rainy weather up to 100%).

Breeze is mostly a positive factor – helps pollination of some species and drying wet leaves after rain, the stronger wind increases evaporation, dries soil, cools down plants and soil, impedes bee activity, and may break branches or uproot trees.

The best sites for fruit crops are the plots sheltered from North-East, North, and West winds. Closed places with a calm atmosphere (sheltered from all sides) are not suitable, however.

7.1.4 Precipitation

Water plays an essential role in metabolism, and nutrient intake, assures the turgor of cells, and is the building substance of the plant body. Water is delivered to plants via precipitation, depending on the local conditions soil water delivery is less important. The following types of precipitation are used with plants or may influence them:

Rain – the main source of water during the vegetation period (in moderate climate conditions), sometimes also part of the winter water supply (warm winters, and important in Mediterranean regions). Rain with lower intensity is better, heavy, intense rain may damage soft plant organs, causes erosion, and disturbs soil structure. Rain enhances the spreading of fungal and bacterial diseases.

Snow – due to insulation properties it protects soil from strong frosts and limits its freezing to big depths, source of winter water supply in col regions, may damage plants mechanically (breakage of branches), and its thick layer may facilitate invading of rabbits and deers to orchards where they bite bark, shoots, and buds.

Hails – cause dangerous damage to fruits, shoots, and leaves, and worsen plant condition. Disturbed quality makes fruits unsuitable for sale.

Dew – in dry regions, its share within annual precipitation amount may reach 10 – 20%, increases relative air humidity, influences relative air humidity and conditions when it occurs affects the ripening of fruits as well as their colour.

Black ice – may cause breakage of branches if too thick.

Fog – the conditions when fog occurs positively affect the ripening of pome fruits but fog shortens the period of direct sunlight, slows the warming of the environment, and enhances the spreading of diseases.

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Picture 42 Flooding due to excessive precipitation causes lack of O_2 in soil and root asphyxia and dying of trees (Paulen)


Picture 43 Snow is source of winter water supply in moderate climates, though heavy load of snow may damage fruit plants (Paulen)

7.2 Edaphic factors

Due to the long life period during which the plant inhabits the site, the soil has enormous importance. Soil gives plants:

- water,
- nutrients,
- air,

and roots anchor the plant in it.

Soils for fruit plants must be deeper than those for field crops, and soil water levels must be deeper also.

Parental substrate – best soils are developed on loess, younger basic ingenious rocks (basalt, andesite, sound stone, and liparite), which produce soil rich in nutrients, and limestone (for stone fruits)

Soil is developed under climatic factor influence on a parental substrate with the contribution of biological factors (plants, edaphon). The best soil types are – chernozem, degraded chernozem (if not too heavy, and not too rich in Calcium – $CaCO_3$ content above 5%), brown soil (suitable for almost all species, mainly medium-heavy, deep, fertile, with pH around 7). The pH level influences the availability of nutrients (mineral soil regime). Pome and berry fruit crops require neutral to slightly acidic soil, stone fruit crops neutral to slightly alkaline, blueberry, cowberry, and cranberry all require acidic substrate.

Table 6 Classification of soil reaction at different pH levels

pH value	Soil reaction
below 4,5	extremely acidic
4,6 – 5,0	highly acidic
5,1 – 5,5	acidic
5,6 – 6,5	slightly acidic
6,6 – 7,2	neutral
7,3 – 7,7	alkaline (basic)
above 7,7	highly alkaline

Slightly podzolic soils (developed in humid conditions with the manifested process of leaching) are less acceptable but they are poor with low humus content. With adequate fertilization, they are suitable for apple trees and currant growing. Typical podzolic sois are inadequate soils for fruit growing, cause during the podzolization process nutrients and organic substances are leached from the upper soil layer to deeper layers, which results in bad topsoil properties.

Leptosols (rendzins) are developed on highly calcareous rocky material and are rich in $CaCO_3$. Due to the conditions in which they are developed and subsoil properties, they are often shallow with poor water retention which makes them suitable for growing only a limited species spectrum.

Alluvial soils are developed near water streams mainly in lowlands, some of them have good mechanical and chemical properties (rich in humus and nutrients), and may be very fertile if the soil water level is not too close to the soil level.

Soil water supplied by precipitation is the main water source for plants. Water consumption of herbs or other small plants can be as low as a few liters a day, but that of big trees 200 – 300 liters a day or more. It depends also on temperature and actual relative humidity.

Soil structure and type together with soil humidity determine the content of the air in the soil. In permeable soils with a good structure water content of 50 – 60% of maximum soil water capacity is optimal for root activity. In sandy soils, water is drained quickly and is substituted in pores by air. Such soil has a low water-holding ability and heat capacity – the temperature of it fluctuates relatively quickly and the organic matter mineralizes quickly as well. Heavy soils hold water for longer and suffer from the lack of air often, they are slowly warming up in spring, crack when drying, grease when wet, and are prone to compacting, which requires cultivation in a proper term. However, trees are anchored better in them.

Soil life is represented by soil microflora and fauna (edaphon). Healthy soil is characterized by a rich spectrum of microorganisms and other organisms. In soils unilaterally exploited, cultivated, and fertilized, as well as those poor in organic matter both the microbial

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diversity and population decrease, and nutrient dynamics are damped which altogether results in soil fatigue. Plants on fatigued soil grow weakly, are stressed, and have worse health conditions, lower productivity, and shorter life period compared to those grown on healthy soil. Removal of the unilateral approach to soil management solves the problem.

Sorptive ability is the ability of soil to bind ions or molecules of different compounds. The bound substances are protected from leaching and create a supply of nutrients available to plants and lower the risk of soil solution high salinity. Among different types of sorption important for plant nutrition, there is physical sorption – binding substances by soil particles via intermolecular forces, chemical sorption – the creation of insoluble substances via chemical reactions ($CaCO_3$, P compounds in calcareous soils for example, and compounds of trace elements at certain pH levels). Chemical sorption decreases nutrient availability for plants. Physical-chemical sorption is caused by electrostatic forces between particles with opposite charges. It is mediated with soil water solution on one side and colloids of clay minerals and organic matter on the other side (organic-mineral sorption complex). In humid soil, bivalent cations are bound more intensively than univalent ones (univalent transit to soil water solution), and vice versa in drying soil. Biological sorption is based on binding nutrients in live and dead microorganisms as well as plants growing on soil. It influences nitrogen dynamics in soil remarkably but participates also in binding other nutrients present in microbial and plant organisms.

7.3 Geographical and topographic factors

These factors are stable characteristics of a given site. Due to it, they are very much influenced by the selection of a region and site for an orchard. However, these factors are quite important because they influence the level and dynamics of other environmental factors. Besides that, they are unique characteristics of a growing site and the combination of them causes a specific microclimate of it.

Latitude and longitude both influence climate – temperature, precipitation, and length of the growing season. In Europe, temperatures decrease from south to north, but there are irregularities in this rule due to the effects of global circulation in the atmosphere, differences in climate types (oceanic vs. continental), and the manifested effect of the Gulf Stream which brings masses of warmer water from tropical zones towards the western and north-western coasts of Europe. Due to that, its effect weakens from west to east. Thus the climate in Europe changes also with the latitude (from west to east), and the western part of the continent is more oceanic while the eastern one is more continental, typical with cold winters and hot summers. The oceanic climate type differs from the continental climate in smaller temperature amplitudes between summer and winter, and day and night amplitudes are smaller due to the heat-compensating effect of seawater masses. These differences are most pronounced at bigger distances.

Altitude influences the climate also, though differences can be manifested in very short distances sometimes. The sites located higher (above sea level) are typically cooler and more humid compared with places located at lower elevations. This causes a shorter growing season with the impact of the zoning of fruit cultures.

Terrain configuration (landscape shapes) influence mainly temperature dynamics and amplitudes, the length of the direct light period and shading, winds, and humidity. Typically, the terrain depressions surrounded by hills are protected from air ventilation and have different temperature regimes from open spaces. They are prone to higher temperature amplitudes and late frosts in risky regions. Sheltered sites may suffer from high pest and disease occurrence. Conditions in slopes also differ from plain terrain depending on their steepness and orientation toward cardinal points. South-faced slopes are the warmest in the Northern Hemisphere (get the highest sum of solar energy) while north slopes are the coolest and more humid due to

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different water balances (lower evaporation). The value of western and eastern slopes differs based on the prevailing air circulation.

Picture 44 Sheltered slopes close to the Hardangerfjord and Gulf stream effect allow fruit production in Northern latitude, Norway (Mallard, tramposaurus.com)

7.4 Zoning of fruit production

Zoning means defining zones within a country in which there are more-less similar conditions for fruit production. Because the environment is very complex there are various approaches used for the determination of those zones. Of course, the decision of using any approach should consider the conditions of a given country. The following methods of zoning can be used:

a) based on geobotanic regions – the occurrence of wild relatives within regions is assessed. The basic idea is that if the wild relative flourishes in some environment cultural forms will also flourish in it.
b) based on soil types – the soil requirements of some species (blueberry, cowberry) may be specific (they need acidic soils), and if the soil does not meet them the plantation should not be established on such soil. For adaptable species, this method does not work.
c) climatic – the simplest – exploits data on meteorological factors which have been gathered on meteorological stations for years. For different species, the zones are created according to their requirements for those factors (mainly temperature and precipitation, and their regimes). The classification of USDA hardiness zones is an example of worldwide zoning based on temperatures.
d) phenological – based on the onset of important phenophases in field or horticultural crops, or agricultural activities (harvest of cereal species, sowing of important field crops) because they reflect the practical impact of climate on plants. Results of long-term observations performed on phenological stations are used. The places on the map of the country with the same datum of the phenophase or agricultural activity are connected with isolines which help define areas suitable for given fruit species.
e) climate-vegetation method – based on the occurrence of species in regions with different climates. In every region with different conditions, an area of 100 ha is selected (with the exclusion of areas of roads, buildings, and non-agricultural land) and the number of

plants of a given species is counted. Suitable regions are those in which the number of species individuals exceeds the determined criteria.

f) ecological-historical method – based on the occurrence of old trees of given species on climatically different sites. The procedure is similar to that used in the previous method, but only old trees are counted. Good conditions allow long survival of trees unless the farming system is not typical with early eradication of senescent trees.
g) cultivar based method – according to cultivar requirements. In countries where there are facilities for cultivar testing and evaluation the data obtained at them may serve as a basis for the selection of best sites for individual cultivars.

7.5 Selection of site for fruit orchard

Fruit plants are most productive if carefully matched with the proper planting site. Very few sites are naturally ideal. To succeed, one may have to overcome some combination of weeds, diseases, pests, poor drainage, low soil organic matter, and poor soil fertility. Each of these can severely reduce the size of fruit harvest and the health of fruit plants. So, it's best to take care of them before planting. Once plants are in the ground, it is very difficult to reduce soil pest populations or correct nutrient deficiencies. The most important year for production is the one before planting when you modify the site to take care of these problems. This is very important, especially if you want to use a low-spray/no-spray approach to pest control.

A previously cultivated site may be preferable to a new site because usually it is not necessary to work the soil and perennial weeds are often already under control. However, soil fatigue may be a problem. It is not recommended to plant strawberries or raspberries where crops susceptible to verticillium wilt have been grown (these include potatoes, tomatoes, eggplants, and peppers – crops of *Solanaceae* family) before.

While gooseberry and currants perform adequately in partial shade, other fruit crops require direct sun for at least six hours a day, preferably more. All fruits require well-drained soil with good water-holding capacity. Although a commercial fruit grower may use tiling or grading and levelling to improve drainage, these methods are not usually affordable for hobby growers. For the best results, simply choose a well-drained site. In some conditions planting on raised beds may solve the problem. To reduce problematic water regimes, increase soil organic matter, and improve soil structure and drainage, growing a cover crop before planting fruit plants is recommended.

In the climatic conditions of Central Europe, improper places are the plots located at foothills or lowest parts of slopes, at bottom parts of narrow valleys, in "frost pockets" (places where cold air accumulates in calm weather), and for some species (Actinidia, apple, and pear cultivars susceptible to premature fruit drop, apricot, peach) open, windy areas. It is important to keep in mind that site-related problems must be solved before planting and during pre-planting soil preparation.

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8 Phenology of fruit plants

During a year there are visible changes or periods of activity in fruit plants which are manifested every year, in stable sequence, though with slight time shifts sometimes. Those periods of activity differ from each other, hence it is possible to recognize and identify them.

In temperate regions, there are two remarkable periods within a year – in the period with adverse conditions for growth – the dormant period, and in the period with conditions suitable for growth activity (temperatures above threshold level, enough water and sunlight) – the vegetative period which is the period with more or less intensive growth. The length and course of the vegetative and dormant periods are inheritable properties of plants – they are adaptations to environmental conditions developed during species evolution.

However, the fruit species grown in temperate regions are originated in different parts of the world with different climates, and their rhythm of activity is not inevitably consonant with the environmental conditions of a given production region. Apricot for example came from regions with a more continental climate and is susceptible to warm spells during dormant period and to temperature amplitudes common in Central Europe during the first phenophases. That inconsonance results in low yields, lower vitality, problems with diseases and a short life period of apricot trees.

There are also differences between cultivars of species adapted to the conditions of a given region e.g. onset of budburst, flowering, fruit ripening which has practical importance. Also, the onset of the periods of specific activity and their length in the same cultivar may be different if grafted on different rootstocks, between trees of different ages or when planted on different sites etc.

Phenophases are observable stages or phases in the annual life cycle of a plant that can be defined by the start and end points. Phenophases generally last a few days to weeks. They are characterized by specific biological activities of plant organisms which can be observed every year, as a part of a gradual process, in the same sequence and are influenced by inner and environmental factors. Phenophases may take their course parallelly.

Phases are phenomena, occurring within phenophases gradually and regularly in individual parts and cell groups of a plant. Phases are localized in the selected part of a plant and can be different within the same plant. For example, phenophase vegetative growth consists of phases as follows – initial growth, strong (intense) growth, and moderating growth.

8.1 Factors influencing the course of phenophases and phases within them

Plant species – different length of vegetative period, onset and length of phenophases caused by different environmental, mainly thermal requirements.

Cultivar – differences between cultivars within species are different, in pome fruit species great differences in ripening time (summer, autumn and winter cultivars), smaller differences in onset and length of the earliest phenophases which may be important in the species susceptible to late frosts.

Rootstock – the influence similar to that of cultivar, though smaller. Dwarfing rootstocks for example cause a shorter period of vegetative growth, and may cause earlier ripening of fruits (apple tree).

Age of plant – young plants have a longer vegetative period and a longer period of vegetative growth than old ones.

Physiological status and condition of plant – sound plants well supplied with nutrients have obviously a longer period of vegetative growth than diseased or stressed plants. These factors are related to the growing technology (fertilization, irrigation, soil management, pest and disease control, pruning etc.).

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Temperature – course of temperatures influences the dynamics of activities within plants remarkably. To express the correlation between temperature and individual processes there is often used Sums of active or effective temperatures – a sum of daily mean temperatures or sum of temperatures above the threshold temperature necessary for starting the process (phenophase).
Water – water is a factor influencing many processes within plants due to its participation in photosynthesis, its role as a constitutional substance of a plant and its role as a transporting medium in organisms etc.

Also, the differences in onset and course of phases have practical importance e.g different onset and length of second flush (intensive activity of cambium) is important for the timing of budding on different rootstock cultivars. Dynamics of apex differentiation may differ between plants of the same species, cultivar and even within the same plant.

8.2 Phenological cycle of fruit plants

Within the round year cycle of temperate woods, there may be recognized following phenophases: 1. budburst, 2. flowering, 3. vegetative growth 4. flower bud initiation and differentiation, 5. fruit development and ripening, 6. shoot maturation, supply substances accumulation and leaf fall, 7. dormancy.

8.2.1 Budburst (sprouting)

The first phenophase which follows the period without visible biological activity. Due to increasing temperatures at the end of Winter sap flow starts and buds start to swell. The processes in buds that stopped during the dormant period (development of generative organs, enlarging of leaf primordia) continue when the temperature exceeds the threshold level. Phenophase ends with leaf rosette creation or with flower opening.

The dynamics of the processes are influenced by temperature predominantly, the onset of the phenophase depends on temperatures at the end of winter and its course on the actual temperature. Phenophase lasts obviously from 15 to 30 days in temperate fruit species. Buds at different positions start to burst at different times – terminal ones earlier, lateral ones and buds on weak basal lateral branches later. As the process continues susceptibility to low temperatures increases. Knowing the processes is important for the estimation of resistance to frosts, adopting measures against late frosts, proper regionalisation of cultivars and timing of treatment with pesticides (against mites or peach curl leaf – *Taphrina deformans*).

Early sprouting species – hazelnut, cornelian cherry, blue honeysuckle, almond, apricot, cherry, elderberry, currants, gooseberry, raspberry, actinidia

Mediumly sprouting species – plum, pear, walnut, apple tree,

Late sprouting species – quince, medlar, mulberry, chestnut

Technological measurements within the phenophase – pruning (mainly stone fruit species), fertilization (1st dose of nitrogen fertilizers), winter spraying against overwintering pests, and against leaf curl in peach.

8.2.2 Flowering

Flowering succeeds to sprouting and creating of leaf rosettes, however, some species flower before leafing. The onset of the phenophase is influenced by temperature and plant species, dynamics of the processes are influenced also by humidity. It starts with the opening of flower buds and ends with the fall of petals.

Due to the different thermal requirements of plant species order of onset of phenophase may vary in regions with different types of climate (continental vs. occidental). In the temperate zone, there are no present problems with flowering due to the lack of chilling hours during winter that may be experienced when growing temperate fruit species in warm

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Picture 45 Gradual budburst and flowering occurs naturally in some apricot cultivars which lowers the risk of late frost damage (Nováková)

climates. After mild winter the species with a short rest period tend to flower relatively earlier.

A flowering sequence of temperate fruit species – hazelnut, cornelian cherry, almond, apricot, peach, cherry, plum, pear, gooseberry, currants, strawberry, apple tree, quince, medlar, actinidia, mulberry, chestnut

In the temperate zone, there is typically only 1 period of flowering a year except for some cultivars of raspberry (primocane cultivars) dewberry, blue honeysuckle and everbearing strawberries. In pears, seldom in apple trees, there may occur a second flowering flush approximately 3 – 4 weeks after the main flowering period – flowers that produce no or parthenocarpic fruits. Among irregularities, there is flowering at the end of summer in apple and pear trees which occurs after hard summer pruning or if the dry summer period is finished with heavy rains (on soils rich in nitrogen) a warm September.

Besides plant species, several factors are remarkably influencing this phenophase:

Temperature – higher temperature speeds up the onset of flowering and its course. Light sandy soils are warming up quickly which causes earlier flowering, similarly, also south-facing slopes typical with earlier flowering are prone to late frosts. Fluctuation of temperatures between day and night hours and night cold slow flowering and decrease below zero may damage flowers.

Humidity – higher humidity slows flowering, wet soil has higher warmth capacity and warms up slowly which causes later flowering. Drought accelerates the drying of stigma and anthers. Cold and humid weather disables pollination activity.

Cultivar – the biggest variation in flowering terms is found in apple tree and pear cultivars (2 – 3 weeks) while small in plums and cherry tree cultivars (6 – 8 days).

There is variation in the onset of flowering within the crown (later flowering on the north side of the crown), and on different parts of branches (later flowering of flower buds produced during the second flush in apricot). Gradual flowering in some apricot cultivars is valuable cause some flowers can escape frost damage. In some species with flowers in

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inflorescences, gradual flowering is a common trait – raspberry, blackberry, currants, elderberry.

Retardation of flowering by a few days is possible with the application of growth substances that inhibit the finishing of the rest period or by late pruning.

For proper pollination warm, dry and calm weather is required. A light breeze is required in wind-pollinated species. Pollen of insect-pollinated plants is not transported by wind to big distances hence wind may play a role in self-fertile plants only.

Technological measures within the phenophase – no soil cultivation, grass mowed to the lowest possible level, irrigation when dry, disease control in special cases (*Monilia laxa*), frost protection, placement of bee or bumblebee hives.

Picture 46 Repeated flowering in apple tree soon after principal blossom period occurs after cold or frosty weather in early Spring (Paulen)

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Picture 47 Repeated flowering in Pinova apple cultivar in Summer (Paulen)

8.2.3 Vegetative growth

This phenophase is related to the division of cells performed by apical meristems. Many new cells are produced in embryonal zones of shoots and roots, produced cells are increasing their volumes and differentiate consequently. Growth intensity within a given plant part may be described by the Gauss curve (phases with different growth intensities)

The phenophase depends on the plant´s physiological status and environmental conditions. In older plants, growth damps out earlier (beginning of summer) than in young ones. A longer growth period and strong growth are typical for plants well-supplied with nutrients (mainly nitrogen) and water. Under such conditions, the growth may continue until autumn. Higher temperature, up to optimum enhances growth, further increase of temperature causes intense evaporation and transpiration with potential water deficit causing damping out to stopping growth. In some situations, growth is renewed at the end of summer after the drought summer period or after hard summer pruning. Vigorous rootstocks enhance a long growth period, in plants infested with diseases or pests, the period may be shortened but damaged leaf area by aphids or rust may result in new growth and prolongs its period until autumn.

Young plants show 2 or 3 periods of growth within the vegetative period - flushes (mainly apricot, peach tree, sour cherry etc.). During second and third flushes shoots are branching, and secondary even tertiary shoots are produced, and sometimes also competing shoots.

The growth intensity of individual organs is different, the highest intensity is found in simple organs (anthers, pistils).

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The growth of roots is not going conjointly with shoots. In spring root growth starts 3 to 5 weeks earlier than phenophase of vegetative growth of the above-ground plant part. I moderate climate (North hemisphere) The most intense root growth is observed in May to June, then it is damped out and is renewed in the period of leaf fall, continuing until November or December if soil temperature allows. In the species that originated in warm temperate regions, the second flush is not remarkable and when the soil cools down the root activity decreases from summer.

Technological measurements within the phenophase are as follows – pest, disease and weed control, 2nd application of nitrogen fertilizers during the first flush and/or foliar fertilization, irrigation if needed, soil management – shallow cultivation after rainy periods, grass mowing, or sowing green manure plants, summer pruning - shoot thinning, pinching etc.

8.2.4 Initiation and differentiation of flower buds

This phenophase begins after the damping of growth, when a good supply of assimilates was accumulated, and lasts for weeks to months, starting with a change of apex (initiation) and continuing with the development of flower primordia until fully developed flower parts. Sometimes the phenophase is repeated within one season (remontant cultivars).

In temperate zone species, the process starts during the vegetative period preceding the year when flowers and fruits will be produced, differentiation stops during winter to be completed before flowering. Species coming from a warmer climate and cultivated in the temperate zone are the exception.

Schemes of flower bud initiation and differentiation

- Initiation: the time when the meristem is committed to forming a flower basement.
  Usually, it occurs early during active vegetative growth. There are no visual clues to this development.
- Differentiation: starts when the terminal growth on a tree stops or damps off.
  Actual flowering structures appear and before entering winter dormancy, flower buds develop to 85% of their size.

The phenophase goes through the following phases: wrinkling of apex and development of scales, creation of individual flower primordia, development of sepals, development of petals, development of ovary and anthers.

Table 7: Examples of the starting times and places of flower bud differentiation

Time of flower initiation and anthesis of some deciduous fruits			
Species	**Beginning of induction or initiation**	**Flowers are borne on**	**Season of anthesis relative to the season of initiation**
Peach	Late June-late July	Lateral buds, 1 yr. shoots	Next spring
Apricot	Early Aug	Lateral buds, 1 yr. Shoots + 2 yr. spurs	Next spring
Cherry, sweet	Early July	Lateral buds, 2 yr. spurs	Next spring
Cherry, sour	Mid-July	Lateral buds, 2 yr. spurs	Next spring
Apple	Mid-June-mid-July	Terminal buds. 2yr.spurs	Next spring
Pear	Early July– early Aug.	Terminal buds. 2yr.spurs	Next spring
Grape	Mid-summer	Compound bur “eye” on last year’s cane	Next spring

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Strawberry	Fall	Terminal bud	Next spring
Blueberry	Late summer into fall	One year and older wood	Next spring
Raspberry	Late summer	Floricanes	Next spring

The sequence of onset of differentiation
1. apple tree, pear, cherry, plum, currants, walnut, rowan (from mid-June approximately),
2. apricot, peach, gooseberry (from late July),
3. strawberry, raspberry, almond (from late September),
4. actinidia, mulberry (in Spring of the production year)

In primocane raspberries, there are two phenophases of flower bud initiation and differentiation, and in everbearing (day-neutral) cultivars of strawberries, the process occurs several times a year.

Among factors influencing the phenophase there are many internal as well as external factors. Some of them may be influenced by a grower to control the fruiting of trees and shrubs.

Specific factors influencing flower bud formation are as follows:

- the vegetative needs to be at a certain stage - a critical node number is required i.e. 20 nodes for Cox's Orange Pippin and 16 nodes for Golden Delicious,
- hormonal balance,
- change in the distribution of nutrients inside the apical meristem,
- the development of flower buds does not start uniformly throughout the tree. In apple tree, the terminal bud of a spur begins its transformation 4-6 weeks earlier than lateral buds.

Species influence the whole annual cycle and activity of plants in different parts of a year. Also, a cultivar is an important factor – in earlier ripening cultivars differentiation starts and finishes mostly earlier, while very late cvs. of pome fruit species in cool climates do not complete differentiation fully and are less productive. The vigour of the cultivar (vigorous varieties differentiate later), and that of the rootstock also are factors. Old, weakly growing trees start to differentiate flower buds earlier, but because of imbalanced production and the need of assimilates only part of flower buds is differentiated completely. For proper differentiation, a big enough leaf area with high photosynthetic production is required. Mechanical damages and infestation with diseases lower photosynthetic production.

In different positions within the crown, differentiation does not start simultaneously – in apple trees terminal buds of brachyblasts differentiate first, while buds on long shoots later, in stone fruit species the process starts in basal parts of shoots and continues towards apical parts, buds on weakly growing shoots start to differentiate earlier. On shoot parts produced during the first and second flushes, the quality and number of flower buds per length unit are different (peach tree, apricot).

Proximity and a big load of developing fruits influence flower bud differentiation negatively. Fruits produce inhibitors and compete with differentiated flower buds for assimilates. Also, the tips of vigorous shoots produce substances inhibiting flower bud differentiation. This mechanism causes an alternate bearing.

In the temperate zone, in years with normal weather conditions, differentiation of flower buds lasts 3 – 3,5 months (pome fruit species) and 2,5 – 3 months (stone fruit species). Because of overlapping processes of fruit development and flower bud differentiation pome fruit species tend to alternate bearing. Uneven productivity between years in stone fruits is more likely the result of adverse environmental factors (late frosts, adverse temperature regime during the winter period), or general exhaustion of the tree.

In general, environmental factors lowering growth intensity enhance flower bud differentiation. Among them, there is dry, sunny weather, and a low supply of nitrogen. Also, some agrotechnological treatments influence flower bud differentiation directly or indirectly. For example soil cultivation, sowing of cover crops in the orchard, sod in the orchard, and irrigation influence soil humidity and consequently growth intensity. Shoot and branch bending and shoot pinching in summer enhance flower bud differentiation as does girdling and strangling of branches before the beginning of the phenophase. Hard pruning and rejuvenation cuts on the contrary suppress flower bud differentiation. Tree forms with a high degree of shading within the crown create adverse conditions for flower bud differentiation.

Knowing the negative impact of heavy fruit load on its quality and also on the processes of flower bud differentiation has led (mainly in pome fruit species) to the implementation of fruit thinning. Rules for fruit thinning are based on the fact that 1 fruit needs 30 – 45 healthy leaves for its development and desired flower bud differentiation. Fruit thinning is done manually, with the help of mechanical tools, or chemically to eradicate excessive fruits before the phenophase begins. Chemical thinning is done soon after blossom while manual up to mid-June. During the phenophase there are performed following technological measures:

- irrigation according to the need of a given crop,
- foliar fertilization (not obligatory),
- summer pruning,
- pest and disease control,
- weed control, soil cultivation or grass mowing in sod system,
- fruit thining before the phenophase or at its very beginning.

8.2.5 Fruit development and ripening

This phenophase starts from zygote creation after egg cell fertilization and finishes when the seeds in the fruit are ripe. Within the phenophase, there are different phases observed during which different processes are going within fruits and there is a different intensity of the processes.

Pome fruit species – fruits are growing more-less evenly within the whole period. After blossom, in May and the beginning of June, intensive cell division is observed in fruit, followed by June fruit drop when fruit growth ceased moderately and fruit is growing mainly due to cell volume increase.

Stone fruit species – developing fruit passes 3 phases – in the first, cell division is intensive and results in quick fruit size and weight increase (apricot, almond, cherries, mainly early cultivars). June drop (in later cultivars) is the second phase when fruit cell division intensity is low but the stone is developing with the embryo inside. The process requires plenty of Nitrogen. Supplying other tree organs than fruits is limited (shoot tips also), and there is a growth gap between the first and second flush. During the third phase, pericarp volume is increasing due to cell size increase (water and assimilate contents are increasing). In peach, for example, the first phase is terminated in 7 – 8 weeks after blossom, the second phase lasts 2 weeks or more, and the third one lasts up to 6 weeks according to the ripening term of a cultivar.

Berry fruit species – fast cell division and fruit growth follow after blossom which continues with cell volume increase. June fruit drop is not observed, however, the berries of some species (currants) are ripening gradually and may drop before being harvested. Also, variable fruit size is typical for some species (black currant, strawberry etc.).

In the initial phase, the anatomy of fruit is simple and the chemical composition is similar to that of young shoots and leaves. Later, permanent structures appear (stone, seed) and parenchyma tissue is developing strongly. Green fruit colour is changing in the final phase to yellow, red or violet. The content of assimilates is increasing towards fruit maturity and the share of individual organic substances is changing – accumulated polysaccharides are gradually

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hydrolysed to oligo- and monosaccharides, pectin and fibre, in general, are increasing first and decreasing in the final phase of ripening, acid content and composition is changing, up to ripening phase, the C vitamin content is increasing, while later it is decreasing. Also, the content of aromatic substances is increasing. Some fruits (quince, medlar, service fruits, cornelian cherry) are high in tannins and their astringent taste disappears due to enzymatic activity when ripening. Also, the substances contributing to cell wall firmness are decomposed which results in flesh softening.

Some fruits on the contrary lose water when ripening (nuts). The phenophase ends with fruit maturity. There are recognized several maturity stages e.g. picking, eating (ready to use), technological, physiological (botanic). Picking mature fruits may have different qualities depending on the specific way of use.

The course of the phenophase is influenced by internal and external factors:
Species and cultivars are dominant factors, Individual species have a more or less broad assortment of cultivars with different ripening periods. The ripening period is the longest in apple tree and pear (summer, autumn and winter cultivars picking terms differ by 3 – 4 months), while the difference in nut cultivars, as well as some miscellaneous fruit species (elderberry, fruit rose, cornelian cherry etc.), is only a few weeks. In pome and stone fruits, very late varieties are not suitable for cooler areas because their quality in such conditions is not satisfactory and productivity may be low. In extra early cultivars of stone fruits, the processes of flesh and seed ripening are somewhat asynchronous and fruits are picked and edible before seed maturity – these cultivars can not be used in traditional breeding as mother components. The growth of their fruits and biochemical changes go much faster than in late cultivars.

Among other factors, there is tree age (older trees – earlier ripening), fruit position within crown or infructescence, rootstock, and environmental factors of course.

Fruits of cultivars grafted onto vigorous rootstock ripen somewhat later and have a longer shelf life (apples). Fruits produced on trees with open, airy crowns have a more intense colour and contain more sugars and other substances contributing to fruit taste. Heavy fruit load results in smaller fruits and lower fruit quality in general.

Lack of water and nitrogen in soil accelerates fruit ripening, however, fruits are smaller and the taste is not satisfactory. Excess of N and cool weather delay fruit ripening. At higher elevations with cooler climates, fruits are ripening later and autumn apple and pear cultivars can ripen in the term typical for winter cultivars. Warmer days alternated with cool nights and fluctuating relative air humidity enhance the skin colouring of ripening apples.

Fruits produced on soils rich in nitrogen in humid conditions are big but their shelf life (e.g. suitability for storage) is shorter. A good supply of nitrogen is crucial in the period of seed growth and stone hardening which is, in Central Europe, in mid of June. High sugar content and good taste are enhanced with a good supply of microelements, and that is why the foliar application of fertilizers with microelements is recommended. Fruit development and ripening may be influenced by phytohormones applied through soil or on leaves.

Good condition of plant and leaf area is a basic condition for the development of a proper number of fruits with the desired quality. During the phenophase, there are performed following technological measures:

- fertilizing with N after fruit setting at the beginning of the vegetative growth period (until mid of the first flush possible), foliar application of fertilizers with microelements, Ca and other nutrients,
- irrigation according to plant needs that finishes 2 – 4 weeks before harvest (regarding species and cultivar),
- summer pruning (to open the crown or to stop growth),
- pest and disease control,

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- soil cultivation, weeding or grass mowing, or sowing of cover crops after cessation of intensive shoot growth.

8.2.6 Shoot maturation, accumulation of supply substances, and leaf fall

This phenophase occurs at the end of the vegetative period. Its start is related to the termination of vegetative growth, the phase with different dynamics in individual shoots. Due to it, the beginning of the phenophase differs within the plant. It ends with a leaf fall.

From the beginning of the phenohase, hydrolytic processes are prevailing over synthesis. The assimilates were deposited in wood, and storage tissues as storage substances (saccharides, malt, hemicellulose, fats, organic nitrogen compounds) during the vegetative period. Malt begins to hydrolyse to low molecule saccharides – glucose, maltose, the mass of soluble nitrogen compounds, tannins etc. increases.

Young cells of newly formed tissues have differentiated before they form permanent structures, Lignin is deposited among cellulose fibres in cell walls which causes tissue lignification. Hydrolysis causes a concentration increase of protoplasm, and day and night fluctuation of temperature cause treading out water from cells which contributes to resistance of colloid proteins against frost damage.

In leaves the amount of chlorophyll decreases, saccharides, P, K compounds, and nitrogen compounds are transported from them to permanent tissues before leaf fall while amounts of silicic acid, $CaCO_3$ and calcium oxalate are increasing. Chlorophyll is decomposed eventually allowing other pigments present in the leaf to become apparent, resulting in non-green coloured foliage (yellow, orange or red). The beginning of leaf drop is when an abscission layer is formed between the leaf petiole and the stem. This layer is formed in the spring during active new growth of the leaf. It consists of layers of cells that can separate from each other. The cells are sensitive to a plant hormone auxin that is produced by the leaf and other parts of the plant. When auxin coming from the leaf is produced at a rate consistent with that from the body of the plant, the cells of the abscission layer remain connected, in autumn, or when under stress, the auxin flow from the leaf decreases or stops, triggering cellular elongation within the abscission layer. The elongation of these cells breaks the connection between the different cell layers, allowing the leaf to fall from the plant. It also forms a layer that seals the break, so the plant does not lose sap. Leaves of some species (peach, apricot, apple, pear) that are not adapted to cool climate fall green before they change colour, often due to frost influence. Leaves of currants and gooseberry on the contrary fall very early in warm and dry conditions.

In young plants, natural leaf fall occurs later than in older ones. Leaves inside the crown fall earlier than those in the crown periphery, bottom leaves of shoots fall earlier than leaves on the top of the shoot. Leaf fall can be accelerated with ethylene, based on this knowledge, specific preparations are used in nurseries to achieve earlier uniform leaf fall allowing an early expedition of trees.

Axillary buds cease growth activity well before leaf fall. Storage substances, starch etc. are accumulated in buds and around them at the end of summer.

The activity of roots is increasing at the end of summer as the soil temperature decreases and humidity increases, they continue to grow, and the maximum activity occurs before the leaf fall. Roots are still absorbing nitrogen which is incorporated into organic substances stored for use during the start of vegetation in the following year.

Biochemical processes in the plant are continuing after leaf fall – hydrolysis of macromolecules to simpler compounds increases plasma viscosity while its activity decreases.

The phenophase is positively influenced by low humidity, low nitrogen availability, and sunny weather. Fluctuation of day and night temperatures and a gradual decrease in temperature result in plant hardening. The good condition of a plant (free of pests and diseases) contributes

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to its preparation for the winter period. Preparation for winter in plants exhausted with excessive yield or suffering from bad nutrition is imperfect.

During the phenophase there are performed following technological measures:

- sowing of cover crop mixture to lower water and nitrogen availability for trees, overwintering cover crops to prevent leaching of Nitrogen
- irrigation after leaf fall or during it to ensure root activity in dry conditions,
- N, P, K fertilization for the next vegetative period,
- spraying with copper fungicides against the pathogens overwintering in orchard.

8.2.7 Dormancy

At the end of the vegetative period, all woody species of the temperate zone enter the dormancy phenophase. Dormancy is plant status with no growth and minimum physiological activity, obviously in the period with adverse environmental conditions. Dormancy is controlled both by genetic and environmental factors.

The phenophase is divided into several phases:

1. Paradormancy – buds become dormant first due to growth substances from leaves inhibiting the activity in buds. The phase lasts from the end of summer until leaf fall. Plant starts the preparation for winter low temperatures. It can be broken when leaves are removed (infestation with diseases, feeding by pests, lack of water or another environmental stress).
2. Endodormancy (plant rest) – the plant is dormant due to a high concentration of inhibitors and lasts from leaf fall until the required amount of cold (hours with a temperature lower than 7 ºC) is accumulated (in Central Europe to the end of December up to mid of January). Enough cold during winter is crucial for flowering quality and uniformity influencing the consequent fruit production. This fact may cause problems in regions with warm winters (subtropical zone). As a result of previous biochemical processes plant is the most frost-resistant and cells are well protected against water loss and cell membrane damage. With the increasing amount of cold, inhibitor concentration decreases.
3. Ecodormancy – plant inhibitors are not effective to keep the plant dormant anymore, and dormancy is caused by adverse environmental conditions (typically low temperature). Ecodormancy advances with heat accumulation toward bud break. Each day warmer than the growth threshold temperature (approximately 7 ºC) shifts buds to bud break. Biochemical changes become more active and plant resistance to frosts is gradually decreasing. Thus the big amplitudes of day and night temperatures at the end of winter can be critical, mainly for species originating in warmer regions. Trees on sheltered sites, valleys and sunny south-facing slopes are the most endangered because of the earlier onset of vegetation. The activity of roots starts earlier than the visible activity of the above-ground part.

During the phenophase there are performed following technological measures:

- fertilizing for the next vegetative period,
- soil cultivation,
- winter sprays against pests and diseases,
- protection from damaging animals – rabbits, deer, or roes,
- planting,
- pruning.

8.3 BBCH scale

More often, another system of classification of processes going during a year cycle is used – BBCH scale. The BBCH scale is used to identify the phenological developmental stages

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of plants. BBCH scales have been developed for a range of crops including fruit crops. Similar growth stages of each plant are given the same code. The BBCH-scale uses a decimal code system, which is divided into principal and secondary growth stages and is based on the cereal code system (Zadoks scale) developed by Zadoks. The abbreviation BBCH derives from the names of the originally participating stakeholders: ***B**iologische **B**undesanstalt, Bundessortenamt und **CH**emische Industrie*.

8.3.1 Basic principles of BBCH scale

The BBCH-scale provides a framework to develop scales for individual crops. Similar growth stages of each plant species are given the same BBCH code. Each code has a description and important growth stages have additional drawings included for a clear interpretation. The first digit of the scale refers to the principal growth stage. The second digit refers to the secondary growth stage which corresponds to an ordinal number or percentage value. Post-harvest or storage treatment is coded as **99**. Seed treatment before planting is coded as **00** (in herbs).

The principal growth stages are the following:

- 0: Germination, sprouting, bud development
- 1: Leaf development
- 2: Formation of side shoots, tillering
- 3: Stem elongation or rosette growth, shoot development
- 4: Development of harvestable vegetative plant parts, bolting
- 5: Inflorescence emergence, heading
- 6: Flowering
- 7: Development of fruit
- 8: Ripening or maturity of fruit and seed
- 9: Senescence, the beginning of dormancy

Below, there is the BBCH-scale for pome fruit that describes the phenological development of apples and pears trees. However, it can serve as an example of BBCH scale for different fruit species.

Table 8: Phenological growth stages and BBCH-identification keys of pome fruit species (Meier et al., 1994)

Growth stage	**Code**	**Description**
0: Sprouting/Bud development	00	Dormancy: leaf buds and the thicker inflorescence buds closed and covered by dark brown scales
	01	Beginning of leaf bud swelling: buds visibly swollen, bud scales elongated, with light coloured patches
	03	End of leaf bud swelling: bud scales light coloured with some parts densely covered by hairs
	07	Beginning of bud break: first green leaf tips just visible
	09	Green leaf tips about 5 mm above bud scales

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1: Leaf development	10	Mouse-ear stage: Green leaf tips 10 mm above the bud scales; first leaves separating
	11	First leaves unfolded (others still unfolding)
	15	More leaves unfolded, not yet at full size
	19	First leaves fully expanded
3: Shoot development	31	Beginning of shoot growth: axes of developing shoots visible
	32	Shoots about 20 % of the final length
	33	Shoots about 30 % of the final length
	3 .	Stages continuous till . . .
	39	Shoots about 90 % of the final length
5: Inflorescence emergence	51	Inflorescence buds swelling: bud scales elongated, with light-coloured patches
	52	End of bud swelling: light-coloured bud scales visible with parts densely covered by hairs
	53	Bud burst: green leaf tips enclosing flowers visible
	54	Mouse-ear stage: green leaf tips 10 mm above bud scales; first leaves separating
	55	Flower buds visible (still closed)
	56	Green bud stage: single flowers separating (still closed)
	57	Pink bud stage: flower petals elongating; sepals slightly open; petals just visible
	59	Most flowers with petals forming a hollow ball
6: Flowering	60	First flowers open
	61	Beginning of flowering: about 10 % of flowers open
	62	About 20 % of flowers open
	63	About 30 % of flowers open

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	64	About 40 % of flowers open
	65	Full flowering: at least 50 % of flowers open, first petals falling
	67	Flowers fading: majority of petals fallen
	69	End of flowering: all petals fallen
7: Development of fruit	71	Fruit size up to 10 mm; fruit fall after flowering
	72	Fruit size up to 20 mm
	73	Second (June) fruit fall
	74	Fruit diameter up to 40 mm; fruit erect (T-stage: underside of fruit and stalk forming a T)
	75	Fruit about half of the final size
	76	Fruit about 60 % of the final size
	77	Fruit about 70 % of the final size
	78	Fruit about 80 % of the final size
	79	Fruit about 90 % of the final size
8: Maturity of fruit and seed	81	Beginning of ripening: the first appearance of cultivar-specific colour
	85	Advanced ripening: increase in the intensity of cultivar-specific colour
	87	Fruit ripe for picking
	89	Fruit ripe for consumption: the fruit has a typical taste and firmness
9: Senescence, the beginning of dormancy	91	Shoot growth completed; terminal bud developed; foliage still fully green
	92	Leaves begin to discolour
	93	Beginning of leaf fall
	95	50 % of leaves discoloured
	97	All leaves fallen
	99	Harvested product

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Picture 48 Examples of Apple tree secondary stages (Rožnovský – Litschmann – Vyskot, 2006)

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9 Pre-planting soil preparation, planting, and soil management in orchards

Regarding the long life period of fruit plantations or orchards when compared to field crops – strawberries have the shortest life period of 1 – 3 years, berry fruit crops, intensive pome and stone fruit orchards 10 – 15 years, and some miscellaneous, long-living fruit species 20 – 50 years or more, preparation of the soil must be complex and careful. A fruit wood rhizosphere may reach well deep (solitary roots up several meters) and wide (some species 2 – 3 times the crown diameter) and roots limit significant amendment of soil properties. Also, the very low solubility of some nutrients makes their supplementation problematic in an established orchard. After planting the trees experience transplant shock, and for the earliest gaining of plant balance, good growth and early fruiting period start it is important to prepare the soil to enable good rooting and high tree survival.

Pre-planting soil preparation must consider soil properties that should be examined, the planted fruit crop requirements, and the process may last different periods. In general, tasks, as follows, should be fulfilled:

- creating a good nutrient supply for a longer period,
- increasing organic matter content and microbial diversity,
- amending pH to a required level,
- making soil fertility even – horizontally (area-wide) and vertically (within expected root horizon depth) at the whole future orchard area,
- deepening a soil profile and improving soil aeration root zone depth,
- destroying (eradicating) as many weeds as possible, especially perennial ones,
- flattening a soil surface,
- getting rid of soil fatigue, if present.

There may be two situations that influence pre-planting soil preparation:

- a virgin land will be prepared – the land where neither fruit crops nor wild relatives have been grown before,
- a land was selected where fruit crops had been grown, more or less prone to soil fatigue causing re-planting disease.

Picture 49 Soil pit made before starting soil preparation allows checking of soil properties in rooting horizons (Paulen)

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9.1 Pre-planting soil preparation of virgin land

Because there is no need to get rid of soil fatigue, soil preparation in virgin land lasts shorter. If soil properties are suitable for fruit crop planting, and there is no need to fulfill the above-mentioned tasks, planting fruit plants is possible without foregoing long-term special preparation. In such a situation, soil with adequate nutrient supply, good soil structure, and plain soil surface are the only conditions necessary for the decision to plant. This is true mainly with fruit crops with shallow root systems.

An example of a soil preparation scheme (for moderate climate conditions) is as follows:

- Year 0, autumn – previous crop harvest, liming (if Ca content needs to be increased), P, K (+ possibly other nutrients) fertilizing, deep ploughing (up to 0,4 – 0,6 m regarding fruit crop which will be planted).

Very heavy (clay) soils and soils with rocky subsoil layers are not subject to deep ploughing causing soil layer mixing because it may result in the upper soil layer worsening. Well-aerated and permeable sandy soils are not ploughed very deeply cause it is ineffective. Deep loosening with a special deep ploughing machine that does not turn the cultivated soil up may be an alternative to common deep ploughing in shallow soils with bad subsoil properties.

- Year 1, season – a crop covering soil well and producing big biomass e.g. fodder pea (*Pisum*), vetch (*Vicia* sp.), fava bean (*Vicia faba*) or maize, sunflower is sown. After harvest sowing of mustard (*Sinapis alba*) or another quickly growing crop, that is, together with barnyard manure or compost (40 – 50 $t.ha^{-1}$), ploughed in the soil in autumn (with mineral P, K , etc. fertilizers unless they were applied in the previous autumn).

Table 9 Plant nutrients of organic fertilizers (source manitoba.ca agricultural service)

Type of manure	Quality	Nutrient content $kg.t^{-1}$ of manure		
		N	P_2O_5	K_2O
Cow barnyard manure	Good*	2,5	1,5	4
	Poor**	1,0	0,5	3
Poultry manure	Good*	5,0	3,0	4
	Poor**	3,0	2,0	3

***well-rotted, but not leached,**
****excessively rotted & leached,**

- Year 2, season – potatoes or vegetables requiring organic fertilizers that should be harvested before September, tillage after harvest at least 4 weeks before planting term (to allow the soil to settle down partly), flattening a soil surface.
- Autumn or following spring – the planting of fruit plants.

If perennial weeds are present, the pre-planting soil preparation period takes 1 year longer – winter grain crops are sown in autumn, harvested in an obvious term in the next year after which weeds are allowed to create a big leaf area, then treated with proper herbicide e.g. Roundup (5-6 $l.ha^{-1}$) or Roundup + NH_4SO_4 (2,5 l + 5 $kg.ha^{-1}$). One month later, the plot is ploughed and prepared to be planted. While the use of glyphosate-based herbicides will be banned in many countries, it is necessary to use other systemic herbicides or agrotechnical methods to kill perennial weeds.

9.2 Pre-planting soil preparation of the plot with fatigued soil

In fatigued soils, a smaller diversity of microbial communities is present with an increased abundance of phytotoxic micromycetes of *Alternaria, Cilindrocarpon, and Penicillium* genera as well as *Fusarium* fungi which produce substances harmful to plants. Plants in those soils produce fewer root hairs and weaker root systems, and growth and

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productivity are decreased. The degree of fatigue is lowered with intercrop growing, green manure crops, and the use of organic fertilizers.

Soil fatigue is the result of unilateral soil exploitation and management, it is crop-specific e.g. it is more expressed if the following species (rootstock) is identical with the previous, while with taxonomically distant fruit crops its manifestation is weaker, and its overcoming is easier.

An example of a recommended soil preparation scheme for fatigued soil is as follows:

- Year 0, autumn – an orchard eradication – thorough removal of fruit plant rests (roots, trunks, branches) is a must, followed with barnyard manure or compost (at least 40 – 50 $t.ha^{-1}$) deeply ploughed in the soil in autumn with mineral P, K , etc. fertilizers to create good to high supply level of nutrients. Alternatively – liming according to need, while organic fertilizers are excluded (never apply organic and Ca fertilizers together).
- Year 1, season – maize or sunflower that is grown for fodder (or equivalent according to a climate, deep rooting crop creating big biomass), after its harvest sowing of mustard (*Sinapis alba*) or another quickly growing crop, in autumn ploughing in its biomass and liming.

Alternatively, cereals (barley, oats, etc.) or crops from *Fabaceae* family (fava beans) with undersown perennial fodder crops e.g. clover (*Trifolium*), alfalfa (*Medicago*), or grass and clover mixture.

- Year 2 – root vegetables (soil cultivation will loosen the soil).

Alternatively, (continuing also during Year 3) – fodder crops are let to grow and produce biomass.

- Autumn of the second or third year – sowing of winter cereals.
- Year 3 or 4 (longer alternative) – cereal crops, harvested in summer, barnyard manure or compost (at least 40 – 50 $t.ha^{-1}$) deeply ploughed in the soil in autumn with mineral P, K, etc. fertilizers.
- Year 4 or 5 – potatoes or vegetables requiring organic fertilizers that should be harvested before September, tillage after harvest at least 4 weeks before planting term (to allow the soil to settle down partly), flattening a soil surface.

If perennial weeds are present, the pre-planting soil preparation period is 1 year longer – winter grain crops are sown in autumn, harvested in an obvious term in the next year after which weeds are allowed to create a big leaf area, then treated with proper herbicide e.g. Roundup (5 – 6 $l.ha^{-1}$) or Roundup + NH_4SO_4 (2,5 l + 5 $kg.ha^{-1}$). One month later, the plot is ploughed and prepared to be planted. While the use of glyphosate-based herbicides will be banned in many countries, it is necessary to use other systemic herbicides or agrotechnical methods to kill perennial weeds.

In any case, soil preparation lasts until it is free of perennial weeds. When preparing soil under berry fruit species a dose of barnyard manure or compost is increased to 60 – 80 $t.ha^{-1}$ and tillage depth may not exceed 0,3 – 0,35 m. pH level is adjusted by liming according to the crop requirements to 6,0 – 6,5.

The soil must be settled down in the term of planting, hence ploughing should not be done later than 3 – 4 weeks before planting. Support should be installed before planting (when done manually) or after planting (when done by machine). The plot must be fenced and routes must be marked before planting.

Picture 50 Rigolation ploughing up to 0,6 m deep during pre-planting soil preparation loosens soil and improves aeration in the deep soil horizon (Paulen)

9.3 Planting fruit trees and shrubs

Selection and purchase of planting material is an important step. If establishing a big orchard or planting a rare fruit crop/cultivar it may be inevitable to find a nursery and negotiate production and delivery of planting material well in advance (2 years in some cases).

The following categories of planting material may be used:

- whip – obviously, a 1-year-old tree with an unbranched vertical shoot allowing training to produce any desired tree form,
- maiden feathered tree – one or two years old tree with a central leader and laterals produced in the same season,
- knip – a two-year-old tree with a trunk and crown formed in different seasons. It is typical of the earlier start of fruiting than the previous tree categories.

According to the height of the trunk, a tree may be classified as a bush (trunk approx. 60 cm), semi-solitaire (approx. 90 – 120 cm), or solitaire (approx. 140 – 160 cm). Young plants may be sold with bud or graft accrued to rootstock without a shoot produced. This type of plant is the cheapest and experiences only small transplant shock, but its development is slower than the previous types. Berry fruit plants are sold as shrubs, often in containers, while trees are sold bare-root mostly. Containers are necessary for plants with succulent or hairy roots susceptible to drying.

Bareroot plants are sold only in dormant stage and are planted from autumn to spring if soil and weather allow it. Container plants may be planted anytime with the exclusion of periods when soil is not prepared or it is frozen (in cold regions).

When selecting a cultivar the market value of fruits, productivity, environmental requirements, and susceptibility of the cultivar should be considered, as well as the term of fruit ripening. For rootstock vigour, soil, climate (mainly water) requirements, and adaptability are important traits.

A tree must have a straight trunk, a required number of laterals (a tree with a crown), a strong rootstock and scion connection, and an ample root system. Smooth, glossy bark without wrinkles indicates good saturation with water important for a high survival rate.

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Picture 51 Root system influences the planted tree's survival and its development after planting, rich well-branched (left) supplies the planted tree with necessary water and nutrients, while the poor root system (right) does not ensure good tree growth after planting (Paulen)

All plants must be labelled with a label indicating plant quality, rootstock and scion cultivar, and producer. Virus-free (VF – free from all viruses) and virus-tested (VT – free from economically important viruses) plants are preferred. Also, a conform (CAC) material is available in many countries (true to cultivar). Conform material is the lowest planting material category.

When handling (transporting, storing) the purchased material water loss must be avoided (roots wrapped in wet tissue or covered with wet peat or sand) until planting time. Plants in containers must be watered and checked regularly.

In temperate climate regions, the autumn planting term is preferred to that at the end of winter or early spring – plants start to root before the soil freezes and start to grow earlier than spring-planted ones. A suitable period for spring planting starts when the soil thaws out and its surface is moderately dried. In heavy soils, a farmer must wait longer because soil keeps water longer and is susceptible to compaction when wet. Delayed term of planting worsens conditions for rooting and decreases survival rate due to an unbalanced water regime (low water intake, and high transpiration due to high temperature). Apple or pear trees stored in climatized chambers may be planted well until late spring, but require thorough aftercare (mainly irrigation) to survive. In regions prone to late frosts a late-term planting (after the risk of frost disappears) may be beneficial.

Holes are trenched just before planting (manually, by drill, or hydro drill). In well-prepared soil the size of the hole able to accommodate roots is satisfactory. When planting with the machine, the holes are trenched and trees are planted within one action. Before planting bare-root plants, it is recommended to cut dried or damaged tips of the roots to create fresh wounds at which a callus will be formed, and new roots consequently. With container plants, it is recommended to soak the container in water before planting for at least an hour. Plants are planted at the same depth as they were in the nursery, berry fruit species by a few cm deeper to get roots into the soil layer that is better protected against drying out. In heavy


Picture 52 Planting walnut trees with the help of mechanization (Višňovský)

soils with the risk of soil drenching in rainy periods, trees are sometimes planted on mounds or raised beds to increase soil aeration around roots. In dry periods it is beneficial to water every planting hole with 5 – 10 l of water, and to plant trees after water is sunken. Shake the tree from time to time when backfilling tree roots in the hole, and press it with the toe then to enable good soil-root contact which is important for delivering soil water to roots. Water the plant thoroughly after being planted and cover the wet soil with a thin layer of dry soil (especially beneficial in spring). Tying tree to a stake keeps root-soil contact (especially beneficial in windy localities).

The above-ground part of a tree (shrub) is pruned soft to hard regarding the ampleness of the root system and planting term – hardier when planting in the late term to smooth the gap between water intake and transpiration. After planting, plants are watered in 7 – 10 days intervals if needed until vigorous growth begins which indicates that the plant has rooted successfully.

As it was indicated above, in intensive fruit production where orchards with high plant density are established, planting machines are used. With them, various operations are combined within one process – rigging up planting furrow, placing trees, covering roots with soil, and pressing soil to roots. Using the machine is justified by high output, and the need for fewer workers. However, it is recommended to check planting depth uniformity and the vertical position of the trunks of the planted trees.

9.4 Soil management in orchards

System of operations within soil management when applied rationally, concerning given soil and climatic conditions, is a prerequisite for stable high yields of fruits with desired quality.

Soil management influences water, aerial and thermal regimes of soil, nutrient transport within the soil, and dynamics of their forms as well as microbial activity, soil edaphon, and plant cover of managed land.

In orchards there are used soil management operations similar to those used in field production, however, their extent and use are remarkably modified by crop and its requirements. Following operations are used in orchards – dragging, harrowing, soil compacting (rarely), loosening with cultivators, rotavators, or disc harrows, shallow tillage, and in some situations herbicides instead of mechanical weeding. For liquidation of organic rests (pruned branches, green manure, weeds) mulching machine is used (organic matter is crushed and spread on the soil surface).

A combination of various practices aiming at gaining and conserving desired soil conditions results in a soil management system. Following soil management systems are used in fruit orchards:

- cultivated fallow,
- sod system (regularly mowed) or more up-to-date soil greening with autochthon herbal species,
- chemical fallow (herbicide system – whole area or herbicide strips),
- cover crops grown for green manure, intercropping,
- mulching.

Any of the above systems have positive and negative sides – technical requirements, time requirements, influence on growth, and yields.

9.4.1 Cultivated fallow

This system was generally used in the XX century in commercial orchards, and it is still used in some commercial orchards and backyard gardens.

It combines shallow tillage (to a maximum of 10 cm depth) after leaf fall regarding the rooting zone of the crop which serves to burry organic rests, kills autumn weeds, incorporates mineral or organic fertilizers into soil, and repeated soil loosening with disc instrument, rotavator, or combinator to a smaller depth (maximum 4 – 6 cm maximum) to eradicate growing weeds, increase soil aeration and to disturb soil crust after rain or irrigation. Soil loosening is not recommended during the blossom period because it increases the risk of radiant frost damage.

The advantages of fallow are:

- simple maintenance with the use of common machine equipment,
- the soil warms up quickly but also cools down (which may be a disadvantage in late frost-prone regions),
- easy applying of fertilizers,
- no competition from weeds,
- stronger growth of fruit plants, big fruits.

The disadvantages are as follows:

- soil structure damaged mainly due to soil cultivation in improper time, and using rotating working parts,
- soil compacting with machinery,
- risk of erosion, mainly on steep lands,
- intense organic matter mineralization which contributes to soil structure worsening,
- accession to the orchard is limited due to soil state (e.g. in rainy weather).

9.4.2 Sod system

The system is established with the sowing of grass mixture on thoroughly flattened soil in inter-rows (typically weakly growing cultivars of grass species – *Festuca rubra*, *Poa pratensis*, *Poa compressa*, *Agrostis stolonifera* in Central Europe after establishing of trees


Picture 53 Fallowing in a Persian walnut orchard (Paulen)


Picture 54 Organic raspberry plantation with sod soil management system (Paulen)

e.g. in the second or third year after planting. In warmer climates, there are other grass species used adapted to specific climates. The system is generally used in commercial intensive orchards, but it is recommended also in extensive low-care orchards. A cheaper alternative, and more natural indeed, is „greening“ by encouraging autochthon herbal species which are left to survive and spread, however, kept under control by regular mowing or with help of sub-lethal doses of herbicides in the initial period.

The grass is mowed regularly, regarding growth rate, to keep its height lower than 10 – 15 cm (mowing 8 to 10 times a season in temperate climate humid regions). The mowed mass is left on soil or raked away to the strip under trees where it serves as a mulch. Because the sod kept in the orchard for the long term creates dense cover and firm divet layer which limits air penetration and exchange of air and warmth between soil and atmosphere, it is recommended to sow grass in every other inter-row and rest of the land manage as fallow. After 3 or 4 years the rows are switched.

The advantages of the sod system are:

- it resembles a natural biosystem with the natural accumulation of organic matter and other processes,
- limited erosion risk,
- lower evaporation from the soil surface,
- better fruit colour (apples, red pears, peach, etc.),
- better fruit storability,

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- access to the orchard is less limited with soil dampness, possible also in the rainy period,
- the system is suitable also for alternative fruit production (bio, IPM)

The disadvantages are as follows:

- regular mowing is needed, which increases costs,
- competition for water and nutrients – due to it the system is inadequate for peach orchards, and berry fruit crops with shallow root systems), and for dry regions,
- air and warmth exchange between soil and atmosphere is limited, higher risk of late frost damage,
- difficult fertilizer soil application,
- higher rat and mice occurrence,
- more perennial weeds,
- incorporation of fallen leaves into the soil with overwintering stages of pathogens is impossible.

9.4.3 Herbicide system (chemical fallow)

It is operated as a full-area system or combined with another soil management system on the plots where the other ways of soil management are impossible or give bad results. A full-area system is possible on plain fields not prone to erosion.

For this soil management system, the plots are preferred with soil well supplied with organic matter (natural, or due to the previous use of organic fertilizers or green manure). The system is aimed at keeping the orchard area weedless with the use of proper herbicides. The use of herbicides absorbed by leaves (contact herbicides) is more environmentally friendly than those applied to soil. In fruit orchards where perennial weeds may be a problem, the use of herbicides based on glyphosate was commonly recommended and their safety was claimed, however, the impact of their long-term use is disputed actually. Herbicide treatments must be done under calm weather and according to the recommendations of producers, and their impact on bees and wildlife should be regarded. Repeated use of the same herbicide may lead to resistance against it, hence it is important to switch herbicides with different agents.

The advantages and disadvantages of the herbicide system are similar to those of cultivated fallow, anyhow, soil aeration and microbial activity are lower obviously. It may be expensive and is often used only in rows under trees – herbicide strips approximately 1 m wide. Chemical weeding has an alternative – the use of flame weeders which kill weeds by heat. Still, it is not completely environmentally sound because this method needs a source of energy.

9.4.4 Cover crops grown for green manure and intercropping

Plants used for green manure help to increase fresh organic matter content in the soil, and its microbial activity and may protect soil against erosion in orchards with fallowing.

A cover crop is a crop planted in an orchard primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife in an agroecosystem, an ecological system managed and largely shaped by people across a range of intensities to produce fruit. Cover crops should not interfere with fruit crop growing technology.

Plants producing ample biomass (green mass and roots), tolerating shade, growing quickly (for effective weed suppression) are used. Also, their water requirements may be a factor in dry regions. In Central Europe, the suitable choice is as follows: legume-cereal mixtures, legumes, crops from *Brassicaceae* family (mustard, rape, etc.), or bee-loved plants (phacelia, Tartarian buckwheat). It is recommended to rotate them. Also, annual weeds before blossom may be used for green manure. Any crop used should not produce fruits/seeds before ploughing in or it may attract mice to the orchard.

Plants for green manure are sown from mid-June to mid-July (after the tree first flush in the temperate zone) so that they do not compete with trees for water and nutrients in the period of active growth. If the period after sowing is humid enough or the orchard is irrigated plants for green manure grow and cover the soil quickly which helps to suppress weeds. Green manure plants are mowed or otherwise destroyed (crushed, treated with discs or so) 2 – 3 weeks before fruit harvest, during the harvest period the rests are crushed more, and after harvest, the crushed mass is ploughed in shallowly. In humid conditions due to the consumption of water and nutrients cover crops may contribute to growth cessation, shoot maturation, and storability of fruits (in pome fruit crops). If trees are too vigorous, earlier sowing of cover crops may help to decrease their growth intensity. In dry regions with mild

Picture 55 Peas grown as cover crop contributes to higher Nitrogen and fresh organic matter content in soil (Paulen)

and humid winters, green manure plants may rather be grown from autumn through winter and crushed before trees enter the vegetative period.

The growing of intercrops in fruit orchards is based on the idea to use the land between trees effectively to produce edible crops or other plant products. Intercrops may interfere with soil cultivation, pest, and disease control, or other operations, and in commercial orchards, their use is quite rare in most countries, while in hobby gardens it is used often. Intercrops may be grown in inter-rows if trees do not shade and suppress them (in the first years after the orchard establishment). When deciding about intercrops, water and nutrient requirements of fruit crops and intercrops must be considered, as well as allelopathy, and pest and disease control timetable. One must avoid residua presence in either of the crops or apply biological means of control.

Suitable intercrops are – annual vegetables and annual flowers which root shallowly and do not require plenty of nutrients. Deeply rooting rampant crops (maize, sunflower, perennial vegetables) should not be grown as intercrops.

9.4.5 Mulching

Soil mulching means covering the soil in a fruit orchard with different materials. It may be applied on a full area or in strips under trees/plants.

This soil management system combines the positive effects of fallowing and sod systems while the main disadvantage is the cost of mulching material and operation related to its transport and placement. Mulching insulates soil thus protecting soil water from evaporation and may help to grow crops requiring humid conditions or rooting in a shallow topsoil layer (berry fruit crops, trees on dwarfing rootstocks).

When using organic materials the soil fertility may be increased and trees on vigorous rootstocks may grow excessively, hence it is recommended as a temporary system from planting to the time they establish well.

The following organic materials may be used for mulching:

- straw, hay, maize rests,
- grass clippings, weeds,
- wood chips, sawdust, crushed bark,
- peat, compost.

These materials are placed onto the soil after the tree blossom has finished because they create an insulation layer on the soil limiting heat exchange between soil and atmosphere and increasing the risk of frost damage. The mulch layer thickness may reach 15 to 20 cm (the thicker layer the more effective weed suppression). Mulch should be ploughed in at the end of the vegetation period or it attracts rats and mice during the winter period. In field-grown strawberries mulching with straw helps to prevent contact of fruits with soil.

The industrial and inorganic materials used for mulching:

- plastic sheet (non-transparent),
- non-woven fabric (black),
- biodegradable materials sprayed or spread onto the soil surface,
- rocks (only rarely)

These are sometimes used as alternatives that are easier to be applied in special situations (nursery production for example). The cost of material is often crucial and influences its potential use. Besides previously mentioned effects, the plastic sheet used in nurseries helps to increase and stabilize soil temperature also. In each of the above materials, sustainability and impact on soil and the environment should be considered, however.

Picture 56 Mulching strawberries grown under cover with a black plastic sheet (Paulen)

Picture 57 Mulching strawberry with straw (Paulen)

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10 Irrigation in fruit orchards

Fruit and nut trees will grow well if well supplied with water. Drought stress will reduce fruit size and stunt growth, especially in young trees. If the water status of the plant is severely deficient the leaves will wilt, curl, and may be sunburned, overall plant growth is decreased. The fruit can be dramatically affected, too, through a reduction in size, water loss and shrivel, and sunburn.

In conditions where dry periods are often expressed establishing of intensive commercial orchard without an installed irrigation system is impossible. Climate change has made irrigation systems a more crucial factor than before. The building of irrigation is influenced by various factors as follows:

Technological – fruit species (influences the amount and timing of irrigation), tree height (influences position of sprinklers if the overhead system is to be installed), rootstock (geometry and depth of rooting influences irrigated profile), length of orchard life period (influences choice of materials and technical equipment of irrigation system), tree or shrub spacing (effects distribution of pipes and water emitters), soil management system (effects need of water, doses, placement of pipes), fertilization (possible use of fertigation), etc.

Terrain – shaping, segmentation, steepness – hydrostatic pressure influences pumping equipment, length of water pipes, and possibly emitter construction. Negligible steepness allows any irrigation system with higher pressure, steepness to 2% allows surface irrigation, and to 6% underground systems or requires specific technical solutions.

Soil – a soaking–in ability and permeability influence irrigation intensity, discharge of water emitters, water dose and frequency of irrigation, and also possible irrigation methods.

Hydrological – capacity, distance, and availability of water source, and water quality affect the economics of irrigation, and technical solutions (filters, irrigation methods)

10.1 Irrigation methods

Irrigation was a part of growing technology in agriculture, as well as fruit growing, throughout its entire history. An increase in knowledge and the technological level was accompanied by changes in irrigation methods. There are used following irrigation methods:

- flood (furrow, basin irrigation),
- sprinkler irrigation,
- drip irrigation,
- localised surface and underground irrigation,
- micro-sprinkler irrigation.

10.1.1 Flood, furrow, and basin irrigation

In these surface irrigation systems, water is moved over the land by simple gravity flow to wet it and infiltrate into the soil. Based on the way of water distribution and the watered area these methods can be subdivided into a furrow, border strip, or basin irrigation. The main advantage of them is simplicity and low requirements for technical equipment. The main disadvantage is low effectiveness (high water consumption), low regulation capability, worsening of soil structure, and extensive weed growth. The system is not used in commercial orchards in Central Europe, modifications are used in hobby gardens - watering with pipe placed under tree crown without exact regulation or manual irrigation using buckets or watering cans.

10.1.2 Sprinkler irrigation

Sprinkler irrigation is a method simulating water delivery and distribution with rain. It may be organized as overhead or under crowns (less often). The system was common in the

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Picture 58 Flood irrigation system in almond orchard (irrigators.org.au)

second half of the XX century. The technical solution is quite simple (hammer sprinklers, and pumps ensuring higher water pressure).

Sprinkler-irrigated trees use the same amount of water as drip-irrigated trees (which is based on how warm is weather and the transpiration rate) plus an additional 20 % for loss to evaporation and non-uniformity of application. The real difference is that with sprinkler-irrigated trees, more water is applied at once, it is stored in the soil for some period, and the entire area is watered. When the whole area under the trees is irrigated, water cannot be saved based on tree size. Weed growth also covers a much greater area.

Another important difference for sprinkler irrigated trees is that soil rooting depth (volume of soil) and soil water holding capacity (soil type, sand, or clay) becomes important since water is stored in the soil. If trees are over-irrigated, part of the water is lost beyond the root zone. Inadequate irrigation is usually caused by running the sprinklers too shortly to wet the entire depth of the root zone or miscalculating the amount of water stored in the particular soil type and too long intervals between irrigation applications.

With sprinkler irrigation, water is not applied daily, but periodically to saturate the soil, which acts as a storage reservoir for water available to the plant. Recent research shows beneficial results from irrigating at or before 50 – 75% depletion of the (soil-stored) available water, then applying what has been used + 20% for efficiency loss. When the overhead system is used, wetting leaves causes a higher risk of disease spreading. The system can be used also for frost protection.

10.1.3 Drip irrigation

The theory and practice of drip irrigation are to provide just what the tree needs every day. Not enough water is applied to leave any in storage in the soil for the next day, so it needs to be watered again the next day. Drip irrigation is a good delivery system because water emitted from drippers positioned on pipes placed along tree rows wet a small area so that weed growth is limited and the system is easily adapted to many landscape situations. Fortunately, only a small fraction (10 – 20%) of the root area needs to be watered to achieve good results.

Soil type or depth has very little influence on drip irrigated trees since the water use rate is determined by weather and trees size. Soil water holding capacity is unimportant due to daily irrigations. Based on tree response from irrigation studies, it has been determined that for young trees it is beneficial to irrigate them by a factor of 2 (double) until the trees reach 70% full cover. It seems that “over irrigated” young trees grow even better than if they receive their daily water use allotment based on evapotranspiration.

For drip irrigation, start irrigating in early spring before much soil moisture has been used because this stored water may be needed later in case the system is accidentally shut down.

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Soil type or depth is almost inconsequential, and only 10 – 20% of the rooting area needs to be wetted for good tree performance.

Apart from high effectiveness, the system has some disadvantages – it requires sophisticated equipment (filters), and good water quality, and may be influenced by terrain configuration (requirements for even water distribution). The system may also be used for fertigation.

Picture 59 Drip irrigation in blueberries grown in containers used also for fertigation (naandanjain.com)

Picture 60 A pool with rain water collected from the roofs of adjacent storage halls serves for drip irrigation in the orchard nearby in Plantex, Veselé pri Piešťanoch ltd., SK (Paulen)

10.1.4 Localised surface (spot) and underground irrigation

Localised (spot) irrigation is a system where water is distributed under low pressure through a piped network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. With this system, pipes are placed directly on the soil, close to plants, and sometimes under a mulching sheet (to decrease water loss). Underground irrigation is based on a pipe system installed in the rooting zone which lowers water loss. Regulation capability is lower, however, and there is a risk of plugging discharge holes with roots. Regulatory drain exploits a system of drainpipes also for water delivery in dry periods. It is quite an expensive system without the possibility of exact water amount regulation, and it is quite rare. It must be installed before the orchard is established.

Picture 61 Underground irrigation piping (irrigators.org.au)

10.1.5 Micro-sprinkler irrigation

Mini (micro)-sprinklers are small sprinklers with water delivered through drip irrigation tubing. Each micro-sprinkler may discharge 10 times more water (or more) than the average drip emitter. The mini-sprinkler system is typically run twice to three times per week with some water held in the soil in storage. Care must be taken to investigate the depth that the irrigation water is reaching for micro-sprinklers since a bigger area is watered and water distribution may not be even.

The system needs sophisticated equipment and high water quality. Besides water delivery for consumption by plants, it raises air relative humidity and decreases air temperature (climatization effect – more intense photosynthesis, lower dissimilation lower evaporation). Disadvantages are similar to those with sprinkler irrigation – enhancing weed growth and creating soil crust on heavy soils after irrigation. Depending on the installation, damage to the pipe system by animals, or mechanization may be a problem. The method is used mainly in countries with warmer, arid climates.

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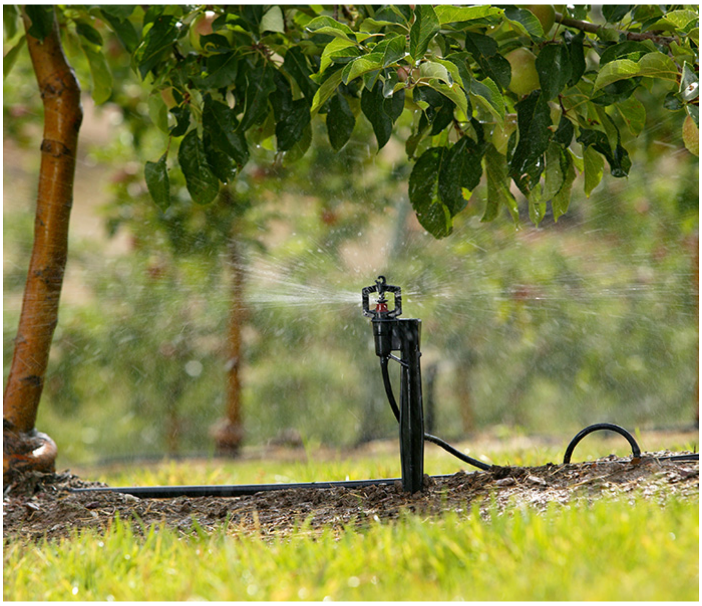
Picture 62 Micro-sprinkler delivers water to plants and influences air temperature and relative humidity (tiirrigation.com)

10.2 Purpose-oriented irrigation

Irrigation in the conditions of an uneven distribution of precipitation during a year is mostly used to supplement water required by plants. However, an irrigation system can serve other purposes, which emphasizes the importance of irrigation. Irrigation systems regarding their purposes can be categorized as follows:

- supplementary irrigation,
- climatization irrigation,
- anti-frost irrigation,
- fertigation,
- irrigation improving fruit quality
- rinsing irrigation.
-

10.2.1 Supplementary irrigation

This irrigation serves to supply the water amount required for basic processes necessary for a plant´s life e.g. nutrient absorption, photosynthesis, growth, transport of substances in plants, and transpiration not delivered naturally, by precipitation. It can help and raises:

- the yield of fruits,
- fruit quality, appearance, and size,
- the exploitation of sites with under-optimal conditions (lack of natural precipitation),
- land saving – the same yield from a smaller area saves costs of soil cultivation, pest, and disease control, transportation, etc.,
- enables sod system use, or cover crops in arid regions where they compete with fruit plants if not irrigated,
- possible use as fertigation, or for protection against late frosts (if a sprinkler irrigation system is used),

Supplementary irrigation can be applied via any of the above-mentioned methods, with different effectiveness, however.

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10.2.2 Climatization irrigation

Serves for lowering air temperature (under 30 °C) in hot periods, raising relative air humidity, which results in higher photosynthetic productivity. This effect is due to sprinkling with small droplets in periods interrupted with breaks lasting a maximum of 15 minutes via sprinkling, micro-sprinkling, or misting. Besides that, this system decreases evapotranspiration which influences water balance positively.

10.2.3 Anti-frost irrigation

When covering the plant surface with water under freezing conditions latent heat of phase change (liquid to solid), 330 Joules from 1 kg of water, is released to warm plant tissues. Also, air relative humidity is increased which decreases heat loss. Irrigation is effective up to –4 to -6 °C, must start at +1 °C, and not be stopped before massive ice thawing starts. The breaks between irrigation periods should not exceed 5 minutes. The recommended intensity of irrigation is 2,0 to 3,8 mm per hour and can be calculated with the use of the following formula:

$$i = \frac{11{,}5 \,.\, h \,.\, v \,.\, /t-2/}{k \,.\, /80 + t_V/} \; [\mathrm{mm.hour}^{-1}]$$

h = height of trees (meters)
v = wind speed (meters per second)
t = air temperature close to the soil surface (°C)
t_V = temperature of the irrigation water (°C)
k = coefficient expressing the water-covered plant surface

10.2.4 Fertigation

Water is a natural medium in which plant nutrients are transported to roots and absorbed. Due to that, it is possible to deliver nutrients to plants with the use of various irrigation systems, mainly those controllable and water-saving – drip irrigation, etc. Fertilizing solution concentration delivered via irrigation is 0,2 – 0,5%. The fertilizers can be aggressive to metallic components of an irrigation system, and this fact must be considered when deciding on the material of which the components are made.

10.2.5 Irrigation improving fruit quality

Sprinkling plants with fruits in the period of fruit ripening improves the colour of fruits and overall appearance, moreover, fruit taste can be improved. Though the irrigation is applied during the final phase of fruit development it should be stopped 2 weeks before the harvest or fruit storability can be affected negatively (apples, pears). This irrigation is not suitable for crops with fruits susceptible to cracking and rotting.

10.2.6 Rinsing irrigation

When using chemical pesticides so-called ballast substances remain on fruits and leaves after spray drying. To remove them, sprinkling with a 2 – 5 mm water dose is applied before harvest. For fruits that will be handled after harvest in grading lines, this irrigation is not necessary because washing fruits is a part of handling with graders. Also, the actual trend when low pesticide doses (because of the high effectiveness of new pesticides) are used, as well exploitation of alternative pest and disease control methods make importance of this irrigation negligible.

10.3 Critical periods of water requirements

The need for water is uneven during the year. There are periods when the negative effect of water deficit on plants is more expressed than in other periods. Generally, the critical periods are those when there are produced tissues with high water content and there is strong growth. There are as follows:

- before blossom,
- period of fruit setting after blossom,
- during intensive fruit growth and before the ripening period,
- after leaf fall (woody species) – roots are very active and absorb nutrients from the soil to create a supply for the beginning of the next season's growth.

10.4 Methods of the irrigation regime management

The irrigation regime expresses a response to 3 questions:
What should be irrigated – which fruit crop, which orchard plot.
When the plant should be irrigated – timing and period of irrigation.
How much water is needed – total water amount and intensity of water delivery.

There are different methods of irrigation management used in orchards that can be classified into the following groups:

Based on the soil moisture – irrigation is applied to reach a certain percentage of field water capacity (water holding capacity of soil). Available water capacity expresses the difference between field water capacity and point of lowered water availability (plant starts to experience problems with soil water intake due to the strong adhesion of water molecules to soil particles). Irrigation is managed to avoid decreasing soil moisture below 50 % of available water capacity. During a sensible period, the optimum is 70 % of available water capacity. The traditional gravimetric method of determination (soil with actual moisture and dried soil weights are compared with hydro limit – soil water holding capacity) is substituted by the use of sensors based on soil water potential for example. They are affordable, yet the most reliable in clayey (medium) soil.

According to water consumption by plant and natural water supply from precipitation – balance methods – expressed for example by evaporation from a free water surface (Class A pan placed in the orchard), ideal precipitation method, methods using mathematical formulas (based on potential evaporation and precipitation amount). Class A evaporation pan is the most simple and may be used in orchards while the methods based on calculations need various parameters to be measured. Also, the calculation of the water balance of the environment is possible using values of meteorological factors.

Physiological methods – devices installed on plants showing their physiological status and indicating the actual need for water allowing the farmer to satisfy it quickly and accurately – though quite accurate they are expensive, and more experimental than practically used by farmers. However, an increase in the use of these methods can be anticipated in the future, not only because of lowering prices but because of water saving.

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Picture 63 Class A evaporation pan is simple tool to estimate water balance of an environment (extension.okstate.edu)

Picture 64 Measuring stem water potential allows to estimate water stress in plant (florapulse.com)

11 Fertilizing fruit crops

11.1 Classification and role of nutrients

For satisfactory growth and production, plants require different elements, predominantly C, H, O, N, P, K, Ca, Mg, S (classified as macroelements or macronutrients), and smaller amounts of Fe, Mn, Zn, Cu, B, Mo, etc. (classified as microelements, trace elements or micronutrients).

Nutrients are absorbed in water solution by roots mainly. Also, leaves and fruits may absorb nutrients (carbon dioxide and other nutrients via foliar nutrition). Root´s role in nutrient absorption is active, and selective, though not completely. Nutrient uptake depends not only on the plant´s requirements but also on the concentration and ratio of nutrients in the soil solution. Besides the elements that are needed by the plant there are some elements (Al, Hg, Cd, Pb, As, etc.) taken in that are not exploited by the plant, accumulated, and may have a harmful influence on human organism when consumed. Nutrient uptake may be influenced by possible antagonism e,g. when a too high dose of K was applied the plant may suffer from Mg deficiency which is manifested by yellowing leaf tissue or Ca deficiency which causes a physiological disorder called bitter pit in apples. Individual nutrients are constituents of various substances in plants and contribute to different processes as follows:

C – all organic substances, assimilation, dissimilation, and other processes in plants,

O – sugars, organic acids, and many other organic substances, assimilation, dissimilation, and other processes in plants,

N – proteins, enzymes, nucleic acids, chlorophyll, various biochemical reactions related to them,

H – in all organic substances and processes related to them, the element in a water molecule which is an important compound participating in biochemical reactions as well as physiological processes,

Mg – in chlorophyll,

Ca – in cell walls, and vacuoles influences pH (together with K and Mg),

Fe, Mn, Zn. Cu, B, etc. – necessary for enzymatic activity,

K – influences osmotic potential and colloid status of protoplast, leaf stigma opening and closure, transpiration, and nutrient transport in a plant.

The absorbed nutrients are exploited in biochemical processes and as components of plant constituents which means that their uptake from soil has relation to the production of the phytomass e,g, roots, wood of trunk, branches, shoots, as well as leaves and fruits. Part of the absorbed nutrients is returned to the soil within a nutrient cycle.

For example, 40 t of apples contains 12 to 36 kg of N, 3,6 to 7,2 kg of P, 40 to 76 kg of K, 1,2 to 3,2 kg of Ca, 1,6 to 2,8 kg of Mg, and smaller amounts of trace elements. Regarding that fruit trees with the same yield may produce different masses of vegetative organs of which only part is together with the nutrients is returned to the soil after pruning, crushing, and mulching the nutrient requirements differ in various orchards. Low production of vegetative mass together with a big production of quality fruits in one plant would be desirable though this goal cannot be achieved. It is because the leaves distributed over the shoots are necessary for the production of assimilates needed for fruit production. This relation indicates that the nutrient exploitation for fruit production by small trees (mainly grafted on dwarfing rootstocks) is more effective.

Table 10 Nutrient content in different fruit species [$kg.t^{-1}$] (Blažek et al., 1998)

Fruits	N	P	K	Ca	Mg
Raspberries	1,1	0,29	1,92	0,69	0,26
Sweet cherries	1,9	0,32	2,63	0,22	0,14
Sour cherries	1,5	0,27	2,18	0,23	0,11

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Plums, gages, peaches, apricots	1,4	0,2	2,40	0,15	0,10
Currants	1,3	0,58	2,84	0,27	0,10
Apples	0,7	0,14	1,50	0,05	0,05

Stone and berry fruits have a higher content of nutrients in fruits than pome fruits due to a higher share of seeds or stones with high dry matter content. Nutrient uptake by the yield can serve as an indicator of fertilizing requirements. The other method to determine fertilizing requirements is leaf analysis. The mature leaves are collected at the end of July or the beginning of August and the content of nutrients in dry matter (in % or ppm) is ascertained and based on the comparison with the recommended values possible deficiencies are determined. However, this method is not fully accurate because the nutrient content in leaves can be influenced apart of their content in soil by weather, pruning, and fruit load. The content of Ca in fruits is important in apples which should be stored for a long period – when lower than 5 mg per 100 grams of fruit risk of bitter pit increases, in fruits high in nitrogen (more than 70 mg of N per 100 g of fruit) the storability is low.

11.2 Soil properties and fertility

The elements are bound in soil by an organo-mineral sorptive complex from which they can be desorbed and be available for plants. Clay minerals and part organic matter in the soil (humic substances, humus) are creating the sorptive complex responsible for its capacity to retain nutrients. Among other factors, nutrient availability is influenced by the pH of the soil solution. Due to that, pH/KCl and the available nutrients (P, K, Mg, Ca, etc.) content are determined when testing the soil fertility. Besides the sorptive complex capacity, its saturation with calcium also the soil biological activity (based on the presence of different microorganisms in the soil) contribute the soil fertility. Microorganisms feed on organic matter and help the nutrient transformation from organic to mineral form and due to the production of organic acids contribute their release from unavailable substances.

Table 11 Classification of nutrient (P, K, Mg) content in the soil based on MEHLICH III extract (Slovík, 2022)

Nutrient	Phosphorus [$mg.kg^{-1}$]		
Content/soil type	light	medium	heavy
low	below 60	below 50	below 40
satisfactory	61 – 95	51 – 85	41 – 70
good	96 – 145	86 – 125	71 – 100
high	146 – 200	126 – 165	101 – 135
very high	above 200	above 165	above 135
Nutrient	Potassium [$mg.kg^{-1}$]		
Content/soil type	light	medium	heavy
low	below 90	below 130	below 170
satisfactory	91 – 150	131 – 200	171 – 260
good	151 – 230	201 – 300	261 – 370
high	231 – 350	301 – 400	371 – 500
very high	above 350	above 400	above 500
Nutrient	Magnesium [$mg.kg^{-1}$]		
Content/soil type	light	medium	heavy
low	below 80	below 110	below 145

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satisfactory	81 – 135	111 – 175	146 – 220
good	136 – 200	176 – 255	221 – 340
high	201 – 300	256 – 340	341 – 470
very high	above 300	above 340	above 470

Soil sorptive ability is assessed via the value of cation exchange capacity (CEC) – a sum of cations that can be displaced (exchanged) into solution from the soil solid phase when the soil is equilibrated with a dilute salt solution; typically expressed in units of mmol..kg^{-1}. The use of this parameter is based on the fact that nutrients are sorbed predominantly as cations (Ca^{++}, K^{+}, Mg^{++}, NH_4^{+}). Besides total CEC also abundance of the individual cations within the saturated capacity is important. The share of the nutrients should be as follows:

K^{+} from 3 to 4% of CEC,
Mg^{++} from 8 to 10 (15 in some soils) % CEC,
Ca^{++} from 60 to 80% CEC depending on the soil type.

The rest of the capacity is occupied by H^{+}, in very acidic soils also Al^{+++} which may be toxic to plants.

Based on the determined CEC value it is possible to specify nutrient doses for fertilizing the soil. The following equations are used:

Dose of Ca (kg per ha) = 0,75 CEC . (target % of Ca saturation – actual % of Ca saturation)

Dose of Mg (kg per ha) = 0,5 CEC . (target % of Mg saturation – actual % of Mg saturation)

Dose of K (kg per ha) = 1,5 CEC . (target % of K saturation – actual % of K saturation)

Sorption is crucial for nutrient stability in the soil and soil fertility from the aspect of long-term supplying plants with nutrients. According to the mechanism of nutrient retention in the soil, there are the following types of sorption:

- mechanical – mechanic retention of particles, aggregates, and coagula containing nutrients in soil pores – medium and heavy soil with many tiny pores (micropores) have a higher portion of mechanical sorption compared to light sandy soils with a high portion of bigger (macro and meso) pores.
- physical – retention of ions and molecules with physical forces on soil phases (solid and liquid) interface. It can be positive – the concentration of molecules on the solid phase surface is increasing, or negative – the concentration of molecules is decreasing which affects their concentration in soil solution.
- chemical – retention due to chemical reactions in which compounds are produced with no or low solubility e.g. phosphorus in alkaline soils forms insoluble compounds, which cannot be leached and are retained in the soil mechanically in consequence.
- physical-chemical – particles with opposite discharge are retained by organo-mineral sorptive complex. This type of sorption allows ion exchange between the soil colloid complex and soil solution. It is considered the most important sorptive mechanism and its extent in the soil is characterised by cation exchange capacity (see above).
- biological – nutrients are retained in microorganisms and other organisms inhabiting the soil (edaphon) due to their uptake from the soil or within a food chain. This type of sorption is selective – organisms take in nutrients based on their specific requirements. Nitrogen depression after applying organic matter with low nitrogen content (straw, wood chips, crushed bark, sawdust, corn straw) into the soil or on it (when mulched) is a manifestation of biological nitrogen sorption.

Soil pH level highly influences nutrient availability. For most of the fruit species slightly acidic (5,6 – 6,5) to neutral (6,6 – 7,2) pH is suitable, in sandy soils lower pH may be acceptable than in heavy ones. At higher acidity, the toxic effect of Al, Mn, and Fe cations may be manifested.

Table 12 Recommended soil pH and required Ca saturation levels in various CEC and soil types (Blažek et al., 1998)

Soil type	Classification according to prevailing particles	CEC ($mmol.kg^{-1}$)	Suitable pH	CEC required Ca saturation (%)
Light	sand	lower than 80	5,5 – 5,9	65
		100	5,8 – 6,3	70
	loamy sand	130	6,1 – 6,6	73
Medium	sandy loam	140	6,4 – 6,7	75
	silt loam	160	6,4 – 7,0	77
	loam	190	6,5 – 7,1	79
Heavy	clay loam	220	6,9 – 7,2	81
	silty clay loam	260	7,0 – 7,2	86
	silty clay	280	7,1 – 7,3	90
	clay	300	7,1 – 7,3	95

Besides organo-mineral sorptive complex also microorganisms (biological sorption) play an important role in nutrient retention in soil which is very useful, mainly with the motile nutrients easily leachable from soil (nitrogen for example) or those hardly available from mineral compounds (phosphorus). Soil organic matter binds Ca, Al, and Fe cations and thus it prevents the creation of insoluble P compounds. Besides that, organic matter plays a role in nutrient cycling, and contributes stability of soil aggregates and clotted soil structure. Organic matter in soil is formed by a broad complex of organic compounds part of which is hardly decomposable – stable humus and part which can be decomposed easily – nutritive humus. When decomposing organic matter microorganisms transform nutrients into available forms. In Central European conditions humus content in the soil above 2% is recommended for common fruit crops.

Nitrogen is an important nutrient with a specific cycle and binds. A big portion of N in the soil is bound to organic compounds and microorganisms. Fruit plants grown in temperate climate zone cannot absorb nitrogen from the air directly, symbiosis with rhizogenic bacteria can help it however (sea buckthorn for example). Total nitrogen content in soil ranges from 0,03 to 0,3%. The mineral form of N is represented by NH_4^+ a NO_3^- ions indexed as N_{min}. Of them, ammonium form is better retained in soil though via nitrification it is transformed to nitrate form. The biological sorption of nitrogen is more important than the other nutrients hence enhancing soil biological activity is advisable. Nitrogen availability can be managed through various technological measures. Its improved availability contributes to higher growth intensity.

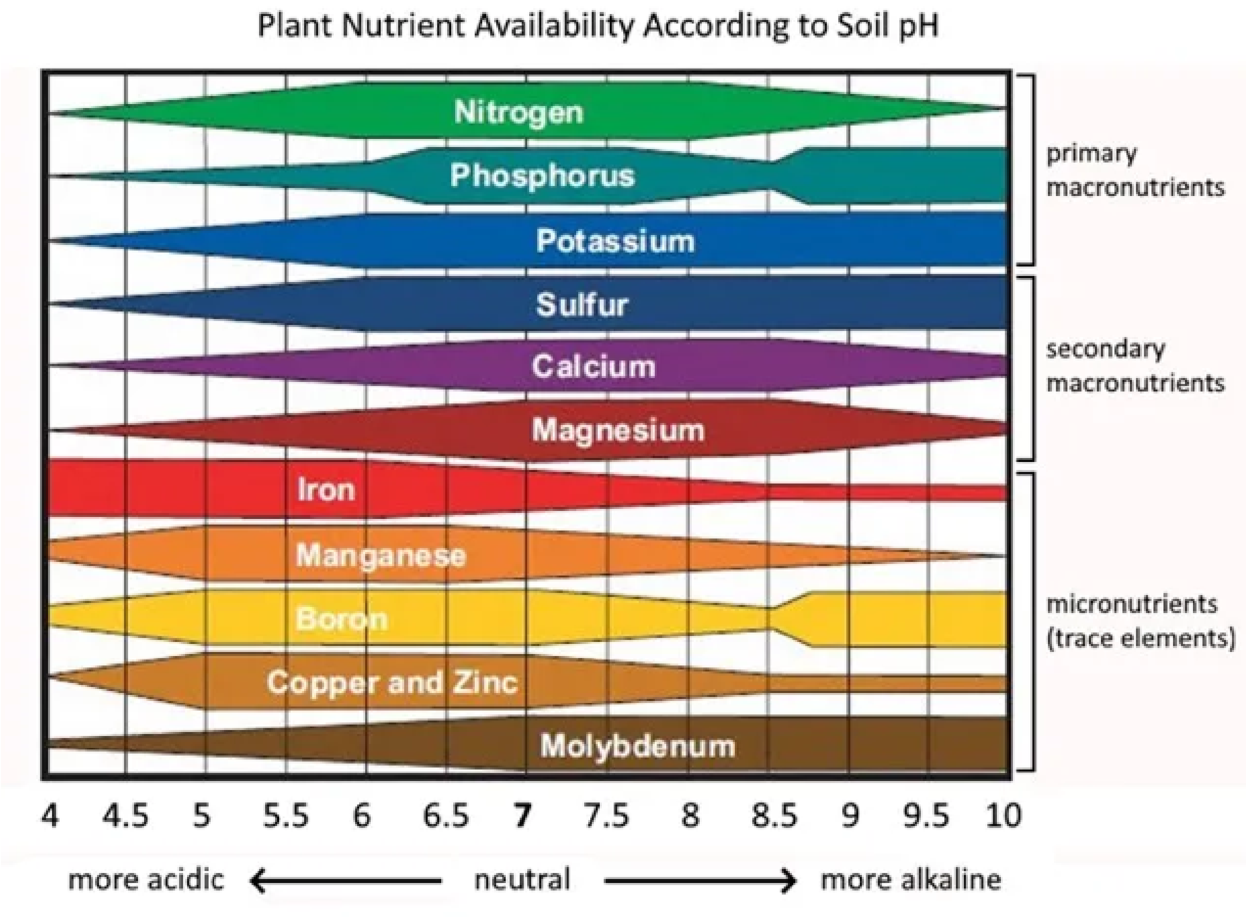
Nitrogen availability can be improved by the following measures:

- soil loosening to enhance a mineralisation of organic matter,
- grass mowing (in sod soil management system) and mulching the soil with the mowed grass,
- reasonable irrigation,
- fertilizing with a small dose of nitrogen to enhance the microbial activity and a mineralisation of organic matter.

Nitrogen can be immobilised to decrease growth intensity and enhance plant tissues maturation by following measures:

- enhancing the growth of competing plants (grass, cover crops, weeds),
- mulching the soil with organic material poor in nitrogen (straw, bark, sawdust, crushed branches, wooden chips).

With the other nutrients, several sorption mechanisms occur, and due to that they are retained in the soil better, and after fertilizing their supply in the soil lasts longer. Some of them may be chemically sorbed though the unavailable forms may be transformed into available ones under some conditions, and plants can utilize them later.



Picture 65 Nutrient availability vs. soil pH (deepgreenpermaculture.com)

11.3 Symptoms of plant nutrient deficiency

Nitrogen – pale to yellow older leaves (base of shoots) while young leaves have often a more intense green colour because they use nitrogen coming from older leaves. Leaves are undersized, internodes are short, overall growth is weakened, fruits are smaller, often better coloured. Leaves change colour early and drop prematurely in autumn.

Phosphorus – small, deep green leaves, possible earlier colouring in autumn, sometimes reddish-purple spots on leaves, fewer flowers produced.

Potassium – older leaves may look wilt, scorched with a dark brown margin, rolling down towards the centre. The deficiency occurs mainly on light soils and is more remarkable under a high nitrogen supply.

Calcium – browning, and dieback of growing tips of roots and leaves. Leaves are curled, margin turn brown, fruit quality is decreased, and fruits show physiological disorders. Lower winter frost resistance.

Magnesium – older leaves turn yellow at the tip and edges leaving a green arrowhead shape in the centre of the leaves, then falling prematurely. The deficiency occurs on soils freely fertilized with potassium, lower nitrogen supply, and low pH as well as on light soils.

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Manganese – yellowing between the veins of young leaves though the pattern is not as distinct as with iron deficiency. Reduction in size of plant parts, dead spots, or patches.
Zinc – small leaves on shoots with short internodes form rosettes on the terminal part of the shoot, yellowing between the veins of the new leaves.
Iron – leaf chlorosis with veins staying green. The deficiency occurs in soils rich in Ca.
Boron – terminal buds die, witches broom form of the shoots, lower fruit setting.
Copper – shoots terminals turn black, necrotic, bend downwards, coarse bark (pear tree). The deficiency occurs mainly on sandy soils and those overfertilized with nitrogen and phosphorus.

Picture 66 Chlorosis and other types of leaf petiole discolouration are obviously reliable signs of nutrient deficiency, specific for individual nutrients (Nováková)

11.4 Principles of fertilizing with main nutrients

11.4.1 Nitrogen

Besides deficiency of N, sometimes its surplus can occur – leaves are deep green, big, thick, plant is vigorous, tissues do not mature well and are susceptible to winter frosts (disproportionality in N, P, K supply), fruit quality is low.

The fertilizing dose is 40 to 70 kg of N per hectare every year (with peach tree 80 kg is recommended) and may be determined based on visual assessment of growth intensity and bearing (yields in previous years and the one expected in the next year). In intensive orchards with high biomass production, the dose can be higher, depending also on the soil fertility. The total dose should be divided into 2 or 3 doses – the first in autumn shortly before leaf fall, the second shortly after blossom on belts below trees and the third by the beginning of summer. Leaf application can be used when supplying nitrogen during vegetation e.g. in combination with pesticides (0,9% urea or multi-nutrient fertilizers). In modern fruit orchards, fertigation is exploited which serves for nitrogen delivery also.

11.4.2 Potassium

Potassium content in soil should be between 2 and 5% of CEC. At higher potassium levels an uptake of Ca and Mg is blocked. Potassium is bound by a sorptive complex and the content of available K can be naturally replenished due to soil minerals weathering.

Potassium doses are counted with the relation indicated above. Potassium sulphate is used for fertilizing predominantly (for berry fruit crops susceptible to chlorine in particular), chloride form fertilizers are applied only in autumn to allow chlorine leaching. Potassium is soil applied, only in acute deficiency, the foliar application is reasonable.

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11.4.3 Phosphorus

A great portion of phosphorus in soil is chemically sorbed, even if soluble forms of P fertilizers are applied transformation to insoluble forms occurs in a short period, mainly in acidic soils. A part of soil phosphorus is absorbed by microorganisms and other organisms (biological sorption) and is released after they die. Its availability is contributed to by organic acids produced by plant roots and microorganisms. P is not leached from the soil, its mobility in soil is very limited, and therefore, plant roots can take up phosphorus only from their immediate surroundings. Due to that, it is important to create a good supply of P in the profile that will be inhabited with roots already in the pre-planting soil preparation period (sometimes, the amount of phosphorus delivered then is sufficient for the whole orchard life period). P availability is very much influenced by soil pH. The optimal pH range for the maximum availability is 6,0 – 7,0. Simultaneous application of P fertilizers and a bigger amount of organic fertilizers containing humic acids is recommended, as also using of P fertilizers, and raw phosphates when preparing the compost which will be applied in the orchard. Other options are - liquid poultry manure applied on belts under trees, NP-sol, PK-sol liquid fertilizers (also for foliar application), and a solution of triple superphosphate injected into the soil.

11.4.4 Calcium and magnesium

Direct uptake of these nutrients is lower than their loss due to leaching from the soil in most of the European regions. Potassium fertilizers, ammonium nitrogen fertilizers, and soil-applied urea all contribute Ca and Mg leaching. Based on soil analysis, Ca and Mg fertilizers are applied every 3 years to substitute spent and leached Ca and Mg. The interval of the soil analysis and fertilizing can be extended up to 6 years in well-saturated soils (soil with CEC over 130 mmol per kg).

The soil saturation is finished with limestone or dolomitic limestone. Simultaneous application of these with barnyard manure is not recommended or it causes a loss of nitrogen. In soils with pH above 7,0 (above 7,2 in heavy soils) and for acidophilic crops, magnesium sulphate or kieserite are used to finish magnesium saturation, or Kamex if also potassium saturation is required.

Calcium is mainly expended by fast-growing tissues with high transpiration and moves up the plant through xylem. It cannot be remobilized from old plant parts and after hard pruning, a disproportional saturation of the plant part may occur. In some apple tree cultivars, lack of calcium in fruits causes bitter pit, mainly in years and conditions when fruits are growing intensely in the final period of fruit development. In acute deficiency of calcium, foliar application of calcium salts e.g. calcium chloride easily absorbed through leaves and fruits is recommended.

11.4.5 Microelements

In soils with pH above 7,5 high in Calcium, chlorosis caused by lack of Fe occurs, often with associated deficiency of Mn, and sometimes Zn. The problem can be solved by soil acidification by the application of physiologically acidic fertilizers e.g. ammonium sulphate. Besides that, a simple fertilizer containing the deficient nutrient (iron sulphate, sodium borate, etc.) or more often foliar application of an appropriate complex fertilizer is used.

11.5 Classification of fertilizers

Nutrients are supplied via fertilizers which are classified according to different criteria:

According to origin: - inorganic (mineral) – manufactured in factories and containing one or more nutrients,

- organic – materials of plant and animal origin under varying stages of decomposition, added to soil to increase the soil organic matter level as well as to increase the soil nutrient level,
- organo-mineral – materials containing components of organic origin (horn, wastes from the food industry, etc.) combined with mineral substances, to enhance the soil's biological activity and nutrient level, often slowly releasing nutrients,
- biofertilizers – materials involving microorganisms added to soil to increase specific microorganisms or to increase the availability of nutrients.

Mineral fertilizers containing only one nutrient are classified as simple, the ones containing two or more nutrients are classified as complex. Fertilizers with microelements are produced also, but those are more expensive. Mineral fertilizers are soil applied in autumn or during the first half of the vegetative period, and to solve acute nutrient deficiency foliar application or fertigation is used. Their role in creating a nutrient supply in the pre-planting soil preparation period is essential.

Organic fertilizers are soil applied shortly before autumn soil cultivation, ploughing in humid soil is best, not very deep (maximum 25 – 30 cm) to assure their aerobic transformation.

According to physical state/form:

- solid fertilizers (granular, pelleted, dust),
- liquid fertilizers,
- gaseous fertilizers (NH_3, CO_2 – not used in fruit orchards in open).

According to the influence on soil reaction:

- acidic fertilizers – increase soil acidity after application (urea, ammonium nitrate, ammonium sulphate, ammonium chloride),
- basic fertilizers – increase soil alkalinity (sodium nitrate, calcium nitrate, limestone).

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12 Modification of microclimate in fruit orchards, protection against adverse abiotic factors

A regular, reasonable yield is the aim of a grower. Reaching it allows an effectively working farmer to be profitable. During a year may occur many factors that decrease or endanger a yield and affect plant conditions negatively. The most frequent negative factors in Central Europe are as follows:

- drought,
- winter frost,
- late (spring) and early (autumn) frosts,
- hails,
- wind,
- pests and diseases,
- various technological failures.

In different climates, the effects of individual factors vary of course. Many of these risk factors are easy to handle when keeping good agricultural practice recommendations and rational routine procedures. Low temperatures, however, occur suddenly very often and may damage fruit plants dramatically, in extreme situations causing a total absence of yield.

12.1 Winter frosts

Frosts during dormant period damage fruit woods only seldom in conditions of Central Europe unless the improper location was selected for the orchard. It suggests the importance of careful regionalisation and site selection, mainly in species requiring warm growing conditions. Due to erratic damages caused by winter frosts no special, stable measures are adopted against them.

Although less common than spring injury, deciduous fruit trees damaged by winter frosts show typical injuries. In northern production areas, when winters are very severe, bark, woody tissue, or buds can freeze. Bark injuries include:

- crotch area injuries, which occur in trees with narrow crotch angles that harden late or incompletely sometimes,
- sunscald injuries on sunny, cold winter days, when clouds then block the sun and cause a rapid cooling towards air temperature that may produce freezing, or under a clear sky where there is a big day/night temperature amplitude (Suth-East injury for example),
- bark splitting, which may occur under very cold conditions,
- trunk, collar, and root injuries that occur when the soil protective effect is insufficient to avoid freezing of those plant parts which are more susceptible than branches.

Tolerance to winter frosts is increased by:

- vitality and good health of fruit plants,
- balanced nutrition and optimum water regime,
- reasonable yield without fruit overload,
- good light conditions (proper spacing, tree form, and pruning),
- suitable temperature regime during autumn (gradual decrease of temperatures with day/night amplitudes and natural leaf fall).

12.2 Spring late frosts

Frosts occurring during the vegetative period occur irregularly and are primarily dangerous for early flowering trees. Their increased occurrence in Central Europe is attributed to climate change. With increased production intensity (high inputs) the importance of measures to avoid the negative effects of late frosts is increasing.

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There are a couple of phenomena related to situations when fruit plants are damaged by spring late frosts.

Picture 67 South-East injury in plum rootstock manifested by necrosis and gumming (Paulen)

Picture 68 Browning of carpels indicates late frost damage in pear flowers (Paulen)

12.2.1 Radiation frosts

Frosts of this type occur on clear nights with little or no wind when the outgoing radiation is excessive and the air temperature is not necessarily at the freezing point. The temperature close to the soil surface is the lowest, drops below zero while the temperature a few meters above the soil can be a few degrees higher. The heat accumulated during the day by soil is released from it and the warm air lighter than the cool one flows up while the heavier cold air flows towards the soil surface. The lowest temperature occurs just before sunrise. The drop in temperature is most remarkable at low air relative humidity.

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Picture 69 Scarce and uneven budbursting due to frost damage occurred in the early phase of budburst (Paulen)

12.2.2 Advection frosts

These frosts occur any time, day or night, regardless of cloud cover, when the cold wind (advection) moves air masses in from cold regions. The obvious direction of advection is from North, North-East, East (from the continent), and sometimes North-West. The freezing effect is strengthened with drying wind effect.

Both types of frosts may occur almost simultaneously (when cold airflow stops during night hours). Most frost-protection techniques can raise the temperature only a few degrees, while some are effective only against radiation frost.

12.2.3 Thermal inversion

Inversion of temperature is a phenomenon manifested by air temperature increase from the ground up to different heights. The temperature differences in various levels within the atmosphere may be remarkable. It occurs during radiation situations, and during winter or after cold periods when warm air starts to flow over the territory an inversion can be very intensive (mainly in winter). Heavy cold air accumulates in valleys, basins (so-called frost pockets), fenced or walled spaces. These formations create a barrier to free airflow and prevent cold air from moving away. Cold air layer often reaches the temperature damaging plants, which is risky mainly the first half of Spring. Wind disturbs an inversion, and this effect is used to eradicate it (mixing of air layers with different temperatures with the help of fans or helicopters).

12.2.4 Cloudiness, smoke, and air pollution with solid particles

These factors create a layer in the atmosphere reflecting infrared (longwave) radiation previously radiated from the soil back to Earth's surface. This effect limits heat loss and causes a less remarkable drop in temperature than under a clear sky.

12.2.5 Dew point

The dew point indicates the temperature to which air must be cooled to become saturated with its water vapour. When further cooled, the airborne water vapour will condense to form liquid water (dew). When air cools to its dew point through contact with a surface that is colder than the air, water will condense on the surface. When condensing a latent heat (enthalpy $h_{lg} = -2257$ kJ/kg) is released which prevents further temperature decrease of a solid on which vapour is condensed. If the value of the dew point is higher than the critical temperature that damages plant organs it is possible to suppose no damage during that night. At low relative humidity (RH) the air temperature is decreasing more rapidly after sunset than at high RH. Therefore, in dry conditions, it is advisable to pay attention to a temperature decrease (with the help of a meteorological station, psychrometer, etc.).

Table 13 Relation between RH and actual air temperature and corresponding dew point temperature (fao.org)

Dew-point temperature (°C) corresponding to air temperature and relative humidity*

RELATIVE HUMIDITY	AIR TEMPERATURE							
%	-2.0	0.0	2.0	4.0	6.0	8.0	10.0	12.0
100	-2.0	0.0	2.0	4.0	6.0	8.0	10.0	12.0
90	-3.4	-1.4	0.5	2.5	4.5	6.5	8.4	10.4
80	-5.0	-3.0	-1.1	0.9	2.8	4.8	6.7	8.7
70	-6.7	-4.8	-2.9	-1.0	1.0	2.9	4.8	6.7
60	-8.7	-6.8	-4.9	-3.0	-1.2	0.7	2.6	4.5
50	-11.0	-9.2	-7.3	-5.5	-3.6	-1.8	0.1	1.9
40	-13.8	-12.0	-10.2	-8.4	-6.6	-4.8	-3.0	-1.2
30	-17.2	-15.5	-13.7	-12.0	-10.2	-8.5	-6.8	-5.0
20	-21.9	-20.2	-18.6	-16.9	-15.2	-13.6	-11.9	-10.2
10	-29.5	-27.9	-26.4	-24.8	-23.3	-21.7	-20.2	-18.6

NOTE: Select a relative humidity in the left column and an air temperature from the top row. Then find the corresponding dew-point temperature in the table.

Picture 70 Automatic meteorological station records values of various meteorological factors necessary for technological decisions including frost protection (Paulen)

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12.2.6 Row orientation

Rows of trees should allow good ventilation of an orchard space (rows within a line of prevailing cold winds are recommended). On slopes, fall line planting helps the stream of cold air to flow out from the orchard (cold air drainage).

12.2.7 Plant condition

The degree of vegetation progress (differentiation of organs) influences the susceptibility of plant organs to frost damage remarkably. Organs rich in water are more susceptible than those with higher cytoplasm concentrations.

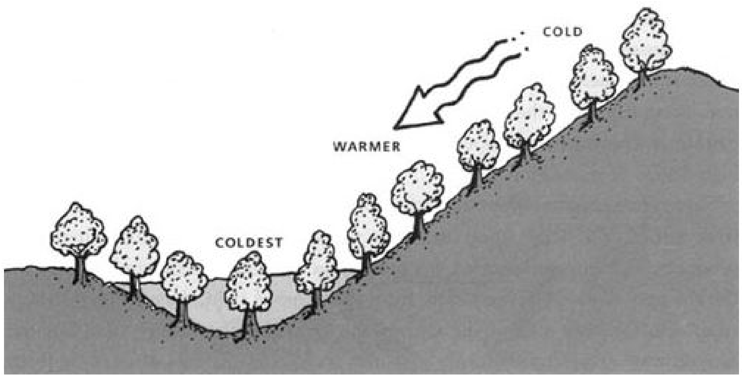
Among species resistant to low temperatures at blossom there are hazelnut and blue honeysuckle (up to -7 ^{O}C), and blueberry (up to -4 ^{O}C). Flowers of some apricot and peach cultivars are less resistant and often damaged due to early flowering dates. Flowers of late-flowering species (raspberry, blackberry, chestnut) are seldom damaged due to the lower probability of frosts during their blossom period.

12.2.8 Soil condition

Bare, compacted, and humid soil allows easy heat exchange with an atmosphere that causes less frost damage compared to conditions of grassed, loosened, and dry soil.

12.2.9 Slope and aspect of the site

Planting early flowering species on slopes facing away from the sun (oriented to the North) delays budburst and bloom which decreases the probability of frost damage. However, less sunlight may influence trees of warmth-loving species (apricot, peach) negatively. Hence only slight slopes with the North aspect (in the Northern hemisphere) are acceptable (shading in winter and later start of the vegetative period, less shade in summer).



Picture 71 Cold air drains downhill and settles in low places where frost damage is the most likely (fao.org)

12.3 Protection against frost damage

The measures to protect from the negative frost effect may be divided into the following categories:

1. Technical (active)
   - air warming,
   - smudging,
   - air mixing,
   - frost protection irrigation,
   - fogging (misting).

2. Agronomical (intermediate) – soil management to help heat exchange between soil and atmosphere.
3. Methods based on physiological and physical effects (passive) – control of ice crystals formation, raising the osmotic potential of cytoplasm, cooling to delay bloom, etc.

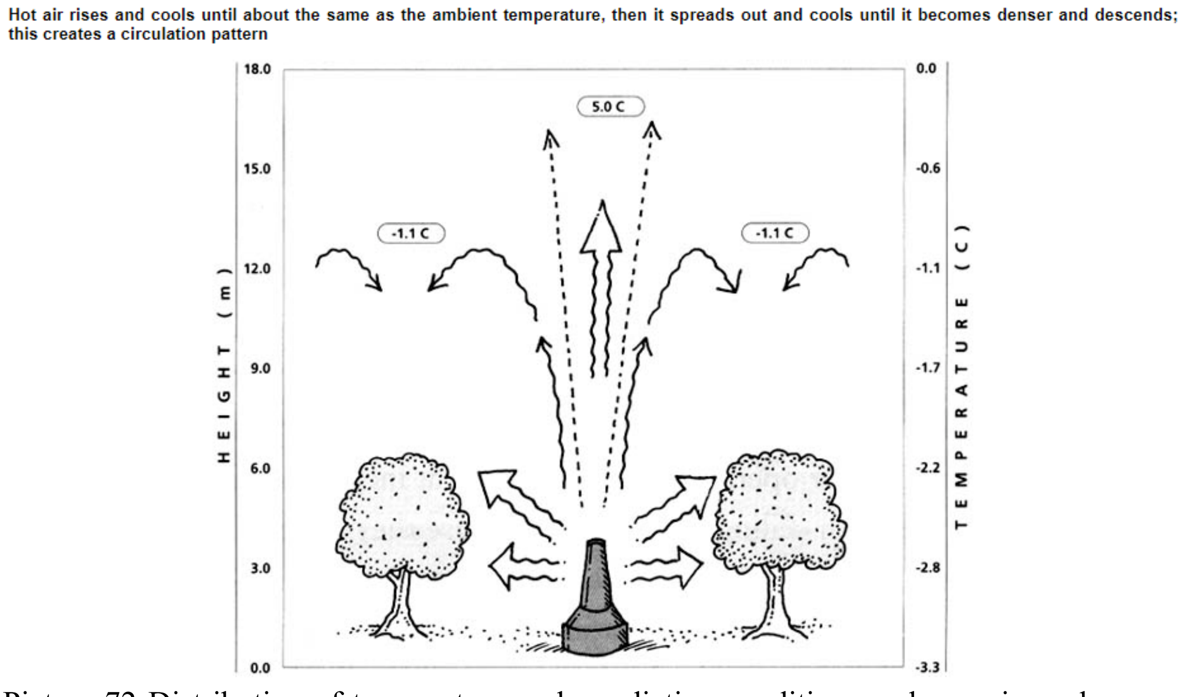
12.3.1 Active technical methods

Active frost protection methods are based on the modification of temperature (air, plant) to prevent its decrease below the critical level that damages plants. They have various effectiveness, often influenced by wind speed, temperature distribution over the atmosphere

12.3.1.1 Air warming

Heating replaces the losses of energy from a crop in a frost situation. For this, a fuel (solid, liquid, or gas) burnt in heaters of various types is used. A basic criterium of any type and procedure is the ability to raise the temperature at least by 4 ^{o}C on the whole orchard area. A high number of individual heat sources assures better temperature evenness
(a minimum of 50 to 100 heaters per ha are recommended). The method works only under radiation conditions (calm atmosphere). The most serious objection against this method is its air-polluting effect. In our conditions, paraffin candles or metallic cylinder vessels filled with wooden pellets and distributed over the orchard area are used as heat sources. Stable heaters using solid or liquid materials as an energy source are classic equipment for frost protection, still used in some regions or different modifications. Mobile burners are commercially available and more effective though more expensive than individual burners distributed over the orchard area. The source of energy in them is liquid gas in tanks typically. High-pressure net systems using heating oil as a medium are not used in Central Europe.

Air warming is energetically and labour demanding obviously, and less operative. When using individual heat sources, a big number of the sources distributed over a big area is needed to assure a desirable protecting effect.



Picture 72 Distribution of temperature under radiation conditions and warming scheme of a heater (fao.org)

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Figure 73 Protection against frost with paraffin candles in a peach orchard (Plantex ltd., Veselé pri Piešťanoch, Slovakia)

12.3.1.2 Smudging

Smoke (solid particles in the air) is produced when burning different organic materials. Before, old tires were used as a source of smoke, however, burning them pollutes the air and is not accepted for environmental regulations anymore. A similar attitude of the public is concerning other ways of smudging. Strawberry producers in Slovakia use wet straw bales placed around and within strawberry plots, fired on risk nights. These combine smoke production with air warming. However, the effectiveness of smoke against frost is not very big, thus the exploitation of solely smoke is not justified.

12.3.1.3 Air mixing

If, in an inversion situation, a layer of warm air with a temperature higher than the critical temperature damaging plant organs is situated above a cold air layer close to the soil surface, and the warm layer is not far from the soil surface, the layers can be mixed with a strong fan or another air mixing equipment (wind machine, helicopter). This method requires high energy and financial inputs, however. For installed fans in orchards, an additional source of energy (liquid gas for example) can be used which increases the effectiveness (and energy consumption also) of the fan.

12.3.1.4 Covering plants with insulation material

Covering with non-woven fabric is used in strawberries during winter (against hard frost when snow absents) and blossom period against late frost. However, allowing access for pollinators (uncovering in proper periods) is important. Also, anti-hail nets installed in orchards may protect orchard areas from heat loss slightly, but spreading nets before or during clossom period is not a common practice (net limits approach of pollinators).

12.3.1.5 Frost protection irrigation

For this purpose, sprinklers are used. Using irrigation to protect plants against frost has the advantage over other methods – water application is generally less expensive, energy consumption is considerably smaller than in frost protection with heaters, labour is only needed to ensure that the system does not stop and the heads do not ice up during the night. In addition to frost protection, one can use sprinklers for regular irrigation, enhancing fruit colour by over-plant evaporative cooling, reducing sun injury by over-plant irrigation, delaying bloom before bud break, fertilizer application, and a combination of these applications.

Like air, water has sensible heat that we measure with a thermometer, and the water temperature increases or decreases depending on changes in the sensible heat content. When the water temperature drops, it happens because sensible heat in the water is transferred to its surroundings, water vaporizes, or there is net radiation loss. As water droplets fly from a sprinkler to the plant and soil surfaces, some sensible heat is lost to radiation, some will transfer from the warmer water to the cooler air, and some will be lost to latent heat as water evaporates from the droplets.

When water droplets strike a flower, bud, or small fruit, the water will freeze and release latent heat, which temporarily raises the plant's temperature. However, energy is lost as latent heat when water vaporizes from the ice-coated plant tissue. This, in conjunction with radiation losses, causes the temperature to drop until the sprinklers rotate and hit the plant with another pulse of water. The secret to protection with conventional over-plant sprinklers is to re-apply water frequently at a sufficient application rate to prevent the plant tissue temperature from falling too low between pulses of water. For non-rotating, low-volume, over-plant sprinklers, the idea is to continuously apply water at a lower application rate but targeted to a smaller surface area. For conventional under-plant sprinklers, the idea is to apply water at a frequency and application rate that maintains the ground surface temperature near 0 °C. This increases long-wave radiation and sensible heat transfer to the plants relative to an unprotected crop. For under-plant micro-sprinklers, which apply less water than conventional sprinklers, the goal is to keep only the ground under the plants near 0 °C, to concentrate and enhance radiation and sensible heat transfer upwards into the plants.

Water delivery onto plants (when using underplant sprinklers) starts at a temperature slightly above 0 °C at the coldest spot of the orchard and continues until massive ice thawing. Irrigation increases air relative humidity and thus decreases heat radiation losses. Water discharge depends on:

- tree size,
- temperature of air and irrigation water,
- the wind speed.

Frost protection irrigation is effective until the air temperature -4 to -6 °C. Among potential adverse effects of irrigation, there are - forming of a big amount of ice (tree breakage) when run for a long period, muddy soil, soil compacting, N leaching, etc.

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Picture 74 Sprinklers for frost protection (naandanjain.com)

12.3.1.6 Fogging

Another method of frost protection is fogging – the creation of an artificial fog with foggers (high pressure and special nozzles) under calm conditions. Water droplets absorb long-wave radiation emitted from a soil surface and re-emit downward long-wave radiation at the water droplet temperature, which is considerably higher than apparent clear sky temperature. Droplets must be small enough (max 0,03 mm) to absorb and reflect radiation and stay in the atmosphere long time. For fogging in fruit orchards there is used a mixture of water and glycerine.

12.3.2 Agronomical methods

These methods are based on soil management that is oriented toward increasing its heat capacity and thermal diffusivity. Their effect is lower than that of active methods of air warming but not negligible, and they are less expensive. The following measures are recommended:

- avoiding soil cultivation – air has low specific heat and is a poor heat conductor. Soil with more and larger air spaces tends to transfer and store less heat. Spaces in soil prevent soil conduction. Therefore, leave the soil compacted before the blossom period, do not cultivate it.

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- irrigation – thermal conductivity and heat capacity of soil is affected greatly by the soil water content. It is recommended to wet the soil to a depth of 30 cm, but the soil should not be saturated. Typically, 25 mm for light and 50 mm of water for heavy soil is sufficient.

- mowing grass or weeds – grass or weeds in orchards reflect more sunlight from the surface and transpire more water which causes a reduction of heat storage in soil and limits the transfer of heat from the soil to the atmosphere during night hours. These effects cause the lower temperature of the above soil atmosphere. The best conditions for radiation from the soil are on bare, compacted soil. Grass or plants should be mowed at the lowest possible height before blossoming in conditions prone to a late frost.

12.3.3 Passive methods based on physiological and physical effects

The principles of the influence of passive methods are various, often mediated, and based on reaching the higher frost resistance of the plant in the period of late frosts. Due to that environmental conditions influence their effectiveness less than in active methods, and passive methods are effective against advective frosts also. Despite this advantage, passive methods are used less often than active methods. Their application in advance, well before the risky period, means that their effect may be not exploited in some situations.

12.3.3.1 Cooling to delay bloom

Operating sprinklers during warm days in winter can delay bloom and hence provide a measure of frost protection. Sprinklers cool the trees because evaporation converts sensible to latent heat, which causes the temperature to drop. Bloom delays of two weeks or more are possible by sprinkling in the period from breaking of rest (beginning of eco-dormancy) to bud break whenever the air temperature rises above 7 °C. Using cold water enhances the effect as does low relative humidity (higher evaporation). The probability of subzero temperature falls dramatically in the spring over short periods, so cooling trees that delays bloom decreases the probability of frost damage. A similar effect is possible with the shading of the orchard area (with opaque canvas) from the breaking rest period which keeps the temperature lower than the threshold level required for budburst.

12.3.3.2 Spraying with nutritive and physiologically active substances

The different nature and probability of late frosts make the rentability of stable frost protection systems sometimes doubtful. Spraying with active substances does not require special equipment and installations and can prevent frost damage even under advection frosts when active methods are ineffective.

The tolerance of tissues to frost is influenced by the concentration of assimilates and the osmotic potential of protoplasts. High water content causes higher susceptibility to frost – pistil after egg cell fertilization is most susceptible. Subzero temperatures around -2 ^{O}C or slightly higher can kill flowers and young fruitlets. Research showed the effects of the following substances:

- spraying with 2,5 – 5% $CaCO_3$ at the beginning of autumn increases frost resistance of buds in the following winter period,

- supplying tissues with nutrients (macro-, microelements), sugars, and growth substances increases frost tolerance due to better vitality and regeneration capacity of the tissues, and also enhances supercooling ability (water in tissues can be cooled below the freezing point without solidification and crystallization) - fertilizers with phytohormones, Atonic, Racine, etc. applied before bloom,

- chemicals to delay bloom – the ethylene-releasing growth regulators increase bud hardiness and delay flowering by 4 to 7 days if applied in the early autumn at the onset of the chilling period. The method has been used on peaches and cherries. Gibberellic acid delays the

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bloom in some crops, but multiple applications are needed, and it is expensive. Gibberellin or alpha naphthalene acetic acid applications during warm days in late winter and spring are known to delay leaf out. Retardation of growth reduces cell elongation. The smaller cells have higher concentrations of solutes, which help them to avoid freezing.

- bacteria control to eradicate ice crystal nuclei – supercooled water (to – 5 ºC or lower) in plant tissues does not create ice crystals unless the process is agitated or when foreign (ice-nucleating) particles are present. Various bacteria (ice-nucleation (INA) bacteria *Pseudomonas* sp., *Erwinia* s., etc.) living on plants help ice-nucleation even at -1 ºC and increase the risk of plant damage. To control this process plants are treated with sprays containing Cu (Champion, Kocide f.e.) or with non-nucleation bacteria which compete with INA, decreasing their concentration and the potential of ice-nucleation. However, the two types of sprays must not be used simultaneously. The spray is applied before bloom and is claimed to protect plant organs for 4 weeks. Also, some compounds which change pH (Na_2CO_3 (0.1 M), Urea (0.5 M) + $ZnSO_4$ (0.05 M), and Urea (0.5 M) + $NaCO_3$ can lower the activity of INA because they are pH sensible.

- IAA application 10 $mg.l^{-1}$ can after a cold period or frost can enhance fruit setting in apple tree, pear, and stone fruit species.

- gibberellic acid (GA_3) at rate 3 $g.ha^{-1}$ applied 1 to 2 days after frost initiates in pear massive parthenocarpy and normal yield.

12.4 Anti-hail protection

Hail is a solid form of precipitation that forms inside thunderstorm updrafts – when raindrops are carried upward into extremely cold areas of the atmosphere and freeze. Hailstones then grow by colliding with liquid water drops that freeze on the hailstone's surface. The hail falls when the thunderstorm's updraft can no longer support the weight of the hailstone, which can occur if the stone becomes too large or the updraft weakens. Forming of hails is supported by atmospheric instability, and high humidity of the atmosphere rich in energy. After falling onto plants, depending on the size of hailstones they damage leaves, fruits, shoots, and even the bark of older branches. The assimilating area becomes smaller, and through the wounds caused by hailstones pathogens can enter the plant tissues. Damaged fruits are not marketable.

Forecasting hail risk is possible, though success hardly reaches 100%. Silvery gray tall clouds probably bear hails while dark clouds are typical rainstorm ones. Sophisticated methods to detect hail-producing thunderstorms use weather satellites and weather radar imagery.

To protect the orchards or nurseries against hail fruit growers use different methods:

- Anti-hail nets installed above tree crowns – on built stable systems (tall pillars) that cover the whole orchard area or individual tree rows are covered (a kind of protecting tunnel is created). The nets are typically spread after blossom and removed before or after fruit picking. The material of nets is plastic with the different mesh, colour (transparent, greenish, grey, black), and various shading effects. Anti-hail nets are not efficient in the event of strong hailstorms. Consequences are potentially even worse than for an unprotected farm because if the net's structure collapses on the crops the grower must replant the entire afflicted area. Nets have also a shading effect against sunburn, can lower temperature amplitude, and prevent possible bird attacks. The system is quite expensive, however.
  Covering the orchard area or single rows with nets can be used to prevent pests (insects, birds) invading onto orchard area, however, proper mesh (the size of holes to prevent pest penetration) and thorough closure of the protected space is necessary. Special nets are reported to be designed for the protection of trees and fruits against fungi (double net film, with slight electrostatic field), and in dusty regions, net´s electrostatic field helps to keep dust and tiny sand grains from fruits.

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- Anti-hail cannon (shockwave generator) – prevents the formation and growth of hailstones by melting altogether. Thanks to shockwaves (strong sound waves produced in short intervals vertically) produced by the hail gun, the supercooling water situated on the external layer of a hailstone is transformed from liquid to a solid state. Therefore, the hail nuclei are not able to melt anymore and remain at a small size which is not dangerous for plants when falling from the cloud. The cannon generates hail-disruptive shockwaves through the use of acetylene or butane gas. The cannon must start to operate at least 20 minutes before an arriving storm. This method is less expensive and therefore more cost-effective than anti-hail nets, however, its noise when operating can raise a problem with public objections in populated areas.
- Anti-hail rockets and other seeding technologies – silver iodide rockets shot into risky clouds influence hailstones formation by adding nuclei (silver iodide particles) inside the cloud. An increased number of ice-forming nuclei causes the smaller size of hailstones which may melt on way down and are less damaging. The method is used in countries of the former Soviet Union, some Balkan countries, China, etc. The method is not very expensive and requires weather radar equipment or weather alert service.

Picture 75 Anti-hail nets installed over apple tree orchard (Paulen)

12.5 Protection against adverse effects of winds

Fruit trees and fruits can be damaged by strong winds mechanically, and there are possible other indirect adverse effects of wind that make protection from wind beneficial. As with other factors, considering the locality effect is a very important and mostly cheap method. Sites prone to strong winds – open, sometimes river valleys and windward slopes, tops of hills are not suitable for establishing an orchard. Also, row orientation allowing free airflow lowers the risk of tree damage.

A basic active measure to protect orchard plots from wind is building windbreaks – vegetation belts next to the orchard plot. The windbreak should consist of 2 – 3 rows of different tree species interplanted with shrubs. Species thriving in local conditions are selected, with different crown structures, and density, allowing quick development of green barrier to wind.

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The barrier must allow partial airflow through or it causes air turbulence and local wind strengthening. Plant species hosting pests and diseases of the crop in the orchard should be excluded. The width of the protected area (within wind direction) is 10 – 15 times the height of the windbreak.

Besides protection against tree damage a windbreak reduces water loss, and pesticide transfer from/into the orchard, can inhibit some pathogens spreading, serves as a shelter for various animal species, and can restrict a public sight into the orchard area.

12.6 Protection from rain

Water on plants is often the medium that allows infestation and spreading of pathogens. Water present on fruits during ripening increases the risk of fruit rot (raspberries, blackberries, etc.) and may cause mechanical damage to fruits by cracking (cherries, plums, etc.). Cracking occurs in periods of heavy rains and excess water in the soil. To protect plants and fruits against rain, various systems are used to prevent rainwater drops from approaching the fruits, however, the orchard management allowing quick drying of the plant surface is important.

Commonly, the systems of anti-rain protection are based on a plastic sheet, naturally waterproof, spread over the trees on a stable construction that has multiple functions obviously – the basis for anti-hail nets, etc. Anti-hail net and anti-rain plastic sheet may be installed simultaneously when anti-hail net being spread over anti-rain sheet increases its stability protecting it from wind gusts. Protection is due to plastic sheet belts spread over tree rows inclining towards margins in the centre of the inter-row which allows water to stream down onto the soil in the centre of the inter-row. Regarding the changed natural water supply over the orchard area, it is necessary to compensate for lower moisture in the belt under tree crowns with artificial irrigation. The protection is important in the period of fruit ripening mainly though due to operational conditions it can be installed over a longer period. In the period of protection, there are somehow limited conditions for pathogen infestation that requires a wet leaf surface.

Picture 76 Protection of sweet cherries against rain by plastic sheets (Paulen)

13 Regulation of bearing and fruit thinning

In favourable conditions, fruit trees tend to set more fruits than is ideal. In years with a heavy fruit load, the amount of nutrients supplied to individual fruits is lower, and due to that fruit size and quality decrease. Also, tree vigour can be depressed, susceptibility to adverse environmental factors may be increased and the process of flower bud differentiation is influenced negatively (low return bloom). It is why in some fruit species alternate bearing is manifested and in some fruit species fruit set regulation is the highly recommended practice. Fruit trees in intensive orchards and backyard orchards are subject to fruit set regulation while bearing of berry and miscellaneous fruit species is not regulated obviously. Also, the fruiting of nut fruit species and cherries is not regulated, though the applied pruning is a treatment that more or less influences the fruiting of any pruned tree or shrub.

To obtain a reasonable yield for trees with good condition it is enough if only a portion of flowers forms fruits as is indicated below:

Fruit trees with big fruits – 2 to 25% in general

Apple tree	2 – 8%
Pear	3 – 11%
Peach	15 – 20%
Plums, gage (with big fruits)	3 – 10%
Apricot	20 - 25%

Fruit trees with small fruits, nut, and berry species – 40 to 100% in general

Almond	20 – 100%
Blackberry	90 – 100%
Blueberry	40 – 95%
Cherry	20 – 75%
Walnut	95 – 100%

Though the effect of fruit set regulation is influenced by species mainly, the other factors are contributing – tree age (low effect in young trees), plant condition (bigger effect in weak trees), and soil fertility (bigger effect on poor, sandy, dry soils), and cultivar (bigger effect in fruitful cvs.)

The following measures are performed to regulate fruiting:

- pruning – before the growth season or blossom it is possible to reduce flower bud set with pruning – removal of part of fruiting wood with flower buds in a dormant period, or removal of branches with developing fruits later (peach, apricot for example). The regulation is based on flower bud recognition and consideration of fruit tree status (age, vigour, overall condition). It is possible to remove ½ to 2/3 of the flower bud set. Pruning is a basic method to regulate fruiting.
- flower or fruit thinning – these treatments mean the removal of a part of flower or fruitlet sets. This can be performed before blossom, during blossom, or later. The sooner the treatment the better its effect.

13.1 Benefits of flower and fruit thinning

Flower or fruit thinning means extra cost for the farmer, but can have different benefits:

- increasing marketable fruit yield – the production of marketable fruits is the basic factor of rentability. With slightly higher costs it is possible to increase the yield of marketable fruits remarkably. Despite the lower number of fruits per tree, the yield must not be lower, or its slight decrease is compensated with higher fruit quality.
- bigger fruits – this effect of fruit set regulation is among the most remarkable. Due to the lower number of fruits on the tree each fruit can be better supplied with water and nutrients, and also with assimilates due to the bigger number of leaves per fruit. Apple size for example

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increases with an increasing number of leaves up to 35 – 40 leaves per fruit, further increase is slow. Change of size is influenced by rootstock, overall plant condition, age, and some other factors. Based on these relations there exist practical recommendations for the final distance of fruits after thinning.

Fruit thinning on its own is not able to increase fruit size. Some cvs. tend to produce small fruits, the same can be observed in old trees, and in them fruit thinning must be thorough and fewer fruits are left on the tree. The water regime of the soil should be considered, the time end extent of pruning (bigger after hard pruning in the dormant period), and the fact that pome trees on dwarfing rootstocks produce bigger fruits while stone fruit trees have smaller ones. Damaged leaf area (by pesticides, pests, diseases, hails) results in smaller fruits. Bigger fruits after the treatment with some pesticides (Captan) are attributed to their thinning effect.

- better fruit colour – thinned fruits do not touch each other and have better basic and blush colour though this effect is influenced also by direct sunlight penetration through the tree crown. This effect is best manifested in cvs. with red fruit colour and can increase the fruit market value.
- better fruit taste – a satisfactory number of leaves per fruit can supply the fruit with needed sugars and other substances and fruits are tastier than on trees overloaded with fruits.
- avoidance of mechanical damage (breakage) of branches – mature trees of some species can bear as much as several hundreds of kg of fruits which require a solid framework of the crown. The tree trained properly can bear heavy yield and the risk of breakage can be negligible, though in some cultivars and crown forms, the farmer cannot rely on it. Some species (pear, apricot, peach) have brittle wood, and branches loaded with fruits can break or split. Fruit thinning can alleviate the risk and decreases the need for branch support. This does not refer to trees on wire supports or other structures.
- vigour enhancement and avoidance of alternate bearing – thinning of fruits helps better supplying the rest of fruits with assimilates, not only fruits but also buds and shoots. Inhibiting the influence of fruits on flower bud differentiation is alleviated which enhances return bloom and prevents alternate bearing. Better supplying with assimilates enhances shoot growth also.
- lower cost of fruit grading after harvest and lower share of non-standard fruits - with manual fruit thinning it is possible to remove malformed or infested fruits which lowers the share of non-standard fruits within harvested yield and creates better conditions for the development of fruits able to reach top quality. On short-stalked apple tree varieties removal of the central ‘king’ fruit is recommended as this may be misshapen and the next largest lateral fruit in the cluster is left to develop. The cost of fruit preparation for a market and grading is lower after proper thinning also.
- better coverage of fruit surface with pesticides – Fruit thinning makes fruits better accessible to pesticide sprays because fruits don’t touch each other. Also, the fruits which may be a source of pests and diseases are removed which lowers infectious pressure within trees.
- lower cost of fruit picking – due to the lower number of fruits after thinning the cost of picking is lower and there is less time needed to pick the yield. This fact is important mainly when the orchard area is extensive (optimum term of picking).

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Picture 77 Overloaded apricot tree produces small fruits and is more susceptible to adverse environmental factors which may shorten its life period (Nováková)

13.2 Methods of flower/fruit thinning

To regulate fruit set several methods can be used, and in case of need the methods may be combined:

- hand thinning
- mechanical thinning – beating by poles or canes, shaking or combing by special machines
- chemical – application of different substances causing fruit drop. The indirect effect of morpho-regulating substances causing the change of branching and flower bud differentiation may be exploited also.

Whatever method is used the thinning should be performed before flower bud initiation and differentiation e.g., in pome fruits not later than in mid-June (in Central Europe) or 4 – 6 weeks after full bloom. Later thinning is less effective.

13.2.1 Hand thinning

Hand thinning is the oldest method of thinning and is the easiest and safest method for removing excess fruits. Begin hand thinning when the fruits are about hazelnut size. Intensive tree forms allow easier fruit thinning than traditional big trees. In pome fruit species only 1 healthy, strong fruit is left per infructescence. There are recommended final distances of individual fruits after thinning – in pome species 100 – 200 mm (depending on rootstock vigour), in peach trees 70 – 100 mm, apricots 50 – 70 mm. In pome trees grafted on vigorous rootstocks, the distance between the neighbouring fruits should be bigger than on dwarfing rootstocks.

When thinning a fruit, the stalk is grasped between fingers and pinched out or ripped. The direction of pulling should be the same as the shoot (branch) growth direction. For fruits with longer stalks or those born in clumps, thinning with harvesting snips is comfortable. For peaches and apricots, fruits cutting through fruit with snips is enough to stop fruit development.

In some stone species (peach, apricot), to regulate fruit load the heading of shoots with fruits can be used instead of thinning individual fruits. A part of the fruiting shoot (seldom that of the branch) is cut off to keep a balance between fruits and leaf area (number of leaves). In peach trees for example, 3 – 4 fruits per long fruiting shoot, 1 – 2 fruits per short fruiting shoot are left to develop, or at least 1 growing shoot per developing fruit is a good proportion. In self-fertile sweet cherry cultivars which tend to set a big number of fruits, half to 2/3 of fruits can be removed by grasping a handful of fruits and ripping them, or cutting off clumps of fruits by snips or pruners.

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Picture 78 Apple fruit thinning by snips (Paulen)

13.2.2 Mechanical thinning

For big trees and big orchards, hand thinning is not practical or is impossible due to time demand. To substitute manual work, beating fruiting branches is possible with poles coated by a rubber or with a rubber hose which diminishes damage to the treated shoots and branches. Fruits are thrown down from the branches, but the result is less precise, and branches, shoots, or fruits on branches are damaged. A correction treatment with the following pruning is often required. Available thinning machines consist of a tractor-mounted rotor equipped with elastic rods radially inserted on a central axis which is rotating when moving alongside a tree row, and combing flowers or fruitlets out. Machine output is 1,3 – 2,5 ha per hour in peaches and apricots. High effectiveness allows fruit thinning in a short period (optimum term of thinning). Also, powered handheld thinning tools are used in some countries to thin flowers of apricots and peaches. The principle of their action is the energetic shaking of branches with flowers that detaches flowers from branchlets. Another principle of fruit thinning used in some machines is detaching flowers with a bold stream of water.

13.2.3 Chemical thinning

The influence of chemical substances on flower or fruit drop has been known for more than 50 years and during that period different chemicals were used for thinning in various countries to a different extent, however.

In general, the reaction on treatment with plant growth regulating substances is variable and the effect depends on the rate of absorption with plant tissue, for example, cool weather, slow drying of the spray mixture, and big leaf area raise the effect. Weak trees are more sensitive to the treatment than vigorous young trees.

The chemical agent concentration is not to be modified freely, even a slight increase of a concentration may cause adverse effects. Added surfactants (agents increasing adhesion of spray to plants), if not recommended by the producer may raise spray chemical uptake and cause plant damage even if a recommended agent dose has been used.

A remarkable effect of the broad factor complex is indicated by differences in treatment effects in different localities and years. The effect is influenced also by application term, weather, tree vigour, leaf area, cultivar, spray concentration, conditions of pollination and fertilization, winter frost damage if present, late frost damage, etc. Mixing thinning agents with other pesticides is not recommended.

In general, chemical substances used for fruit load regulation can be classified into the following groups:

- caustic compounds,
- synthetic auxins,
- substances inducing ethylene production in the plant.

13.3 Chemical thinning in commercial orchards

Despite the disadvantage of the fact that the effect of chemical thinning is influenced by numerous factors and is not 100% guaranteed, the advantage of time-saving treatment makes their use in commercial fruit orchards quite a common measure.

13.3.1 Apple tree

Chemical thinning is aimed at lowering the number of fruits and overcoming the tendency to alternate bearing strongly manifested in many apple cultivars. Sometimes, a combination of several growth substances is needed (synthetic auxins) to reach the goal. Cultivars of the Delicious group for example tending to set a big number of fruits require higher doses of agents than less productive cultivars. The following agents/products are used to thin flowers/fruits in apple trees:

To thin flowers, products based on salts or acids (caustics) are used which burn the stamens and stigma of the flower which prevents successful pollination. In different countries, there are used:

WILTHIN – applied in the term when at least 70 – 80% of flowers are in blossom and central (king) flower of the inflorescence has been pollinated. The agent must not be applied when a big portion of petals have been fallen or it can damage fruits (scars on their surface) and is ineffective. It is not combined with surfactants and applied above 29 ºC.

THINEX – applied when 60 – 80% flowers are in blossom, at a temperature above 12 ºC. Should not be applied during night and wet weather.

THINSET (ammonium thiosulphate) – the agent is most efficient if applied between 20% and 50% of flowers open. In years with an extended blossoming period (cool weather), 2 sprays may be needed, the first when 25% of flowers are in blossom, and the second when most of the flowers on spurs have opened. It should be applied at a temperature above 10 ºC, at higher temperatures the doses of the agent should be increased because of fast drying.

To thin fruits after blossom, synthetical auxins are used as follows:

NAD – not suitable for cultivars of the Delicious group. It is sprayed 7 to 14 days after full blossom with surfactant added. In cool weather, the treatment is delayed to the term when fruits reach 2 – 3 mm diameter, optimally at a temperature higher than 18 ºC. To improve the effectiveness of the treatment combination with Carbaryl-based preparation (Sevin) is recommended.

NAA – the treatment with added surfactant is recommended 15 – 25 days after full blossom. In cool weather, delayed treatment is recommended, in the term when fruits reach 10 – 15 mm diameter. A combination with a Carbaryl-based agent is recommended. NAA is ineffective at temperatures lower than 10 ºC.

CARBARYL (Sevin) – is an insecticide with the recommended term of treatment 10 to 25 days after full blossom when fruits reach 3 to 20 mm in diameter. Carbaryl is highly toxic to bees and predatory mites used in pome species, mainly when used for the first time. In such a situation, it is recommended to exclude the trunk and bottom parts of scaffold branches from the treatment. It should not be used at a temperature lower than 21 ºC, or it can cause seed abortion and the development of small fruits (parthenocarpy).

Among the ethylenogene substances, there is Etephon (Ethrel agent) that can be used in combination with NAD (AmidThin) approximately 3 weeks after blooming.

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13.3.2 Pears

In pears, fruit thinning is less often used compared to apple trees. Use of preparations for young fruit thinning 3 weeks after full bloom or parthenocarpy can be initiated. Due to the tendency to parthenocarpy thinning effect can be lower compared to apple trees.

13.3.3 Stone fruit species

Chemical fruit thinning has been examined mainly in apricot and peach, and plums also. Spraying with Carbaryl (0,1% concentration) is recommended in the term immediately after the blossom has finished. This causes a drop of 60 to 70% of young fruits.

Also, spraying with gibberellic acid (GA_3) was examined before the blossom period, with a concentration of 250 mg per liter. The effect was very good, but because it is a very early treatment it is rather risky in regions where late frosts occur.

14 Preparation for fruit harvesting, yield estimation, harvesting and postharvest manipulation with fruit

Yield is a final element of the chain repeated every year, starting with soil cultivation in autumn, continuing with winter or early spring pruning of fruit woods, fertilizing and care of trees (or shrubs) during the vegetative period. It is influenced by numerous factors, of which the technological ones may be managed, some of them only when establishing orchards (cultivar, rootstock) while some factors are out of control.

14.1 Yield estimation

Already long before the term of harvest, during the vegetative period, it is possible to estimate yield more or less accurately. Crop yield estimation is an important task in orchard management. Accurate yield prediction helps growers to improve fruit quality and reduce operating costs by making better decisions on the extent of fruit thinning and organizing harvest based on the labour force required for the harvest. It helps the packing segment within the farm or packing industry if the fruit is manipulated in external packing houses because managers can use estimation results to optimize packing and storage capacity. Typical yield estimation considers historical data, weather conditions, and the results of fruit counting in multiple sampling locations. The benefits of accurate estimation are as follows:

- knowing the expected yield offers a basis for recruiting the necessary number of workers for the period of harvest,
- preparation of appropriate supply of packings, material, transport means, storage capacities (short or long term),
- allows providing for necessary market capacity (regarding available marketing channels for different product uses),
- information for fruit producers union, for protection of the inner market from excessive imports etc.

Yield estimation is performed several times during the vegetative period, obviously:

1. after blossom and fruit setting,
2. after the June fruit drop,
3. 4 to 2 weeks before harvest.

The later the estimation term the higher accuracy of it. At any term, it is important to make notes of estimated data and bases for their determination to make their comparison with real yield and correction in future possible if needed.

Yield estimation is based on farmers´ experience from yield estimating in previous years. Comparison of actual flower or fruit load with the previous corresponding data and the yields enables more accurate yield estimation in the actual year.

The simple traditional sampling procedure and estimation are as follows: randomly distributed 10 trees are selected for sampling (in uneven and big orchards selection of more trees is recommended). Fruits on the selected trees are counted, and the average number of fruits per tree is calculated. Multiplying it by the number of trees per ha gives the total number of fruits per ha which is multiplied by the average fruit weight (obtained from pomological literature or based on the previous yields in the given orchard):

$$Y = f \,.\, w_f \,.\, t / 10^6$$

Y = yield ($t.ha^{-1}$)
f = average number of fruits per tree
w_f = average fruit weight (g)
t = number of trees per ha

The accuracy of this method is higher if standard conditions for fruit development are created (irrigation, crop set regulation etc.). Because a smaller size and bigger number of fruits increase time consumption for performing this method, it is used in crops with bigger fruits.

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For berry fruit crops, some miscellaneous fruit crops etc., fruits or infructescences are counted on a fruiting branch, their average number is multiplied by mean fruit or infructescence weight, then multiplied by the number of fruiting branches per plant, and the output is multiplied by the number of plants per ha which gives the yield per ha.

The indicated manual method is time-consuming, labour-intensive and inaccurate. To deal with this problem, there are developing computer vision-based systems for automated, rapid and accurate yield estimation. One of the systems, that was developed in the U.S.A. uses a two-camera stereo rig for image acquisition. It works at night time with controlled artificial lighting to reduce the variance of natural illumination. An autonomous orchard vehicle is used as the support platform for automated data collection. The system scans both sides of each tree row in orchards. A computer vision algorithm detects and registers fruits from acquired sequential images, and then generates fruit counts as crop yield estimation. In Europe, another method is offered as a service for farmers – a special software processes pictures taken by the camera of a mobile phone by counting the fruit number and size sent by a farmer to the servicing centre and it returns the expected yield. The service can be used to estimate the dynamics of fruit size growth also.

14.2 Determination of proper picking term

Incorrectly set picking terms may result in a lower yield - too early picking date – fruit are still growing, too late – part of the yield is lost due to fruit drop, worse quality and taste – lower sugar and aromatic substances contents, improper quality for given processing method, worse appearance – unsatisfactory fruit colour, lower storability, and shelf life. These facts may cause marketing problems and lower price, which may result in low or no profit.

When determining ripeness there are several ripeness stages recognized:

- botanical (full) maturity – seeds in the fruit are completely developed and after placing in suitable conditions they can germinate naturally,
- dessert maturity – eating quality e.g. fruit taste, consistency, aroma (sensorial traits), attractiveness for a consumer are at their peak,
- technological maturity – fruit has an optimum quality for a given processing method. Because of different processing methods (drying, freezing, fermentation, juice extraction, etc.), there may be different levels of technological maturity of the same fruit,
- picking maturity – fruit condition is best for picking which means that this term is different for fruit intended for dessert use, processing (different way), storage, transportation to distant markets, etc. Some fruits (winter apples and pears) are not suitable for eating when picked, and they pass postharvest maturation until they reach the quality that makes them suitable for eating (dessert maturity).

There are different methods used for the determination of the proper picking date. When deciding about the method, it is important to consider crop, cultivar, use of fruits after harvest, locality, and available equipment must be considered also.

The most common methods and determination criteria are overviewed below.

14.2.1 Number of days from full blossom to picking maturity

It was found that the length of the period from blossom to picking maturity is approximately the same under given climatic conditions and is only slightly influenced by weather in different years which can be used to determine a picking term. It is good to combine this method with the other methods, however.

Length of the period may be found in pomological literature or determined based on several years of observations in the given locality which may be more accurate.

14.2.2 Easy separation of fruit stalk from fruiting branch

The ability to separate from a branch is tested with moderate turning of fruit towards the fruiting branch. If the fruit separates easily it is the proper time to pick it. Fruit should not be twisted around the stalk axis (neither when picking it) or the stalk may be pulled out and fruit may rotten consequently. The method may be used in apples, pears and some stone fruits.

14.2.3 Fruit drop

Some fruits may drop when ripened. The start of dropping indicates the proper time for picking, however, picking must succeed as soon as possible, mainly in cultivars liable to dropping which may cause a problem (windy and rainy weather may result in an excessive fruit drop). It can´t be applied in species with fruits firmly attached to branches or stalks (strawberry, medlar, sea buckthorn etc.) or whose fruits lose quality when dropped.

14.2.4 Seed colour and development

Seeds of ripened fruits are well developed, swollen, and have brown skin. However, it is not true in extra early cultivars of apple and pear whose fruit and seed development are asynchronous (seed development is slower), and the method does not apply to them. It is most suitable for autumn and winter cultivars of apple and pear that are picked at the time when dessert maturity has not been reached yet. In walnut, change of testa (seed skin) colour indicates the time for treatment trees by ethylenogene agents to unify fruit ripening for mechanized picking.

14.2.5 Fruit colour

The colour of the fruit skin is mostly a reliable indicator of fruit ripeness, mainly in early cultivars of pomes, most of the stone fruits, and berry fruits. Proper picking date is when the basic colour reaches desired hue and intensity, in some fruits (peaches, apricots) the change of the hue may be visible. In the fruits with a blush, the colour of fruit born in different parts of the crown may be very variable which limits the reliability of the method. In some fruit-producing regions, farmers use colour scales to evaluate the fruit ripeness stage and determine proper picking dates in individual cultivars.

To ensure the green colour of skin and higher acid content, fruits of some apple cultivars are picked prematurely when the change of hue is not visible yet. Fruits picked too early may shrivel and wilt during the storage period, however (Delicious apple group).

In pears, a corky look of lenticels is a good indicator of maturity – in unripe fruit, they are white while in ripe fruit they are brownish and slightly raised.

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Picture 79 Tart cherry fruit colour is relatively reliable trait to decide about the date of harvesting (Paulen)

14.2.6 Fruit flesh firmness

Flesh firmness is quite a reliable indicator of maturity if there is known the proper firmness for a given cultivar. Apple firmness is used worldwide as a measure of the ripeness and condition of the fruits. Firmness is measured with a pressure tester (penetrometer). Because fruit ripeness within an orchard (even within a single tree), and fruit tissue turgor is variable during the day, it is recommended to consider the following facts:

- fruits from the crown periphery are likely firmer than those from the crown centre,
- fruit size is also a factor, the larger the fruit, the softer it is. For accuracy it is important to test fruits of standard size,
- the temperature of the fruit can influence the results of pressure tests. Firmness tends to be slightly lower when the fruit is warm than when it is cold. It is important to test fruit at the same (standard) temperature,
- the number of tested fruits influences the accuracy of the testing result. For the apple harvest date, it is recommended to test 10 apples per orchard, to do 2 – 3 tests per fruit and test one set of fruits per week. For storage, 20 apples are tested per growers´ (suppliers´) lot, 2 – 3 tests per fruit before placing in the storage chamber, and for appearance during postharvest ripening, 10 apples per growers´ lot are tested, allowed to ripen 10 days at 18 °C, 95% RH, 2 – 3 tests per fruit.

To be able to use the data in the following years, it is recommended to make notes on the measured firmness and corresponding appearance of fruit in the postharvest period.

This method is very useful for informative sensorial determination of fruit for processing,

14.2.7 Composition of fruits

Based on chemical analysis one can obtain data on the actual content of selected substances (sugars, acids, vitamins etc.) in fruit and compare them with the standard contents in the desired maturity stage.

The ripeness of apple fruits is commonly tested with the starch-iodine test. In ripening apple starch is converted to simple sugars. In the test, Iodine binds with starch granules and develops into a dark purple colour. Less purple colour means less starch and more simple sugars – the fruit is more ripe.

14.2.8 Sensorial assessment of fruit ripeness

Although there are sophisticated instruments to quantify the concentration of individual flavour molecules in fruits, the best yet simple measure is probably the human mouth. Always sample a few bites of fruit before picking to make sure that they have the desired varietal characteristics. Picking a good-tasting fruit is important for all operations, but for those with direct marketing businesses, the flavour might be the most important characteristic for determining harvest maturity.

It combines a sensorial assessment of taste, texture, aroma and appearance of the fruit. Assessment is naturally approximate to that of the customer, hence is suitable for fruit intended for dessert use, but not for fruit that should be stored.

Stone fruits are picked at the peak of their taste (for immediate sale on close markets) or 2 – 3 days before (for distant markets) as are also berry fruits. Fruit of apple and pear summer cultivars are picked 1 week before the mature stage. If they are left to ripen on the tree fruit flesh is mealy or soft and has a dull taste.

14.3 Organisation of harvesting

Besides the determination of the proper picking date, it is important to plan the number of workers for the expected harvest period. As a basis for planning a picking output is used which can be as follows:

- apples – 500 – 2000 kg per person a day,
- pears – 370 – 1300 kg,
- peaches and apricots 150 – 300 kg,
- cherries 30 – 75 kg,
- raspberries – 30 – 45 kg,
- strawberries – 60 /10/ – 100 kg.

However, harvesting efficiency is, besides a human factor, influenced by many other factors – the size of trees, size of fruit, fruit load, picking tools, distances between trees and bins (people that walk do not pick), soil condition and actual weather.

Also, a picking method and organization of work influence harvest effectiveness. Harvest may be done in one term, or in several terms, which is more suitable for fruits ripening continuously over a longer period (strawberry, blueberry, raspberry, blackberry, mulberry etc.). Also, fruits of crops ripening more-less simultaneously (apple, pear, peach, apricot, plum) have a somewhat extended period of ripening and picking in several terms gives the chance to pick fruits at the desired condition (highest quality), and increases a total yield, but also the cost of picking.

Different accessory materials and tools may be necessary for fruit picking, as well as packages and machines for the transportation of fruits to a store or marketplace.

Fruit picked manually is placed into picking bags, buckets, bins or, if required from the market, into the packagings (trays, bowls etc.) which the fruit will be marketed in. Manual picking is performed by unprotected hand, or hands in gloves (for picking fruits with waxy or hairy skin and intended for dessert use). Some fruits are picked with the help of scissors/snips (elderberry) or are knocked or shaken from trees with poles (nuts).

Bins can have different capacities and accommodate from several kilograms to 250 – 350 kg of fruit. While wooden bins were used before, plastic ones are commonly used because of availability, weight and easy and perfect disinfection. Bulk bins are used for apples or pears to be stored, and for fruits to be processed.

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Picture 80 Bulk bins prepared for apple fuit harvest (Paulen)

Picture 81 Mechanized harvesting of walnut fruits (Paulen)

14.4 Harvesting methods in different fruit crops

To ensure high harvesting effectiveness, different harvesting methods are adopted for individual fruit species considering fruit traits, their distribution on plants as well as fruit final use.

14.4.1 Pome fruit

Traditionally, fruits were picked manually into buckets, baskets or picking bags which are emptied into bulk bins in inter-rows. Summer cultivars susceptible to bruising may be picked and placed in bins in which fruits will be sold to a customer. This method can be used also in organic farms where smaller quantities of fruits are produced.

Picking can be organized in several stages (so-called thinning harvest), mainly if fruits ripen slowly and the farmer wants to pick fruits at their best, although this practice is less common in pome fruits than in stone fruits. In traditional orchards, the trees are tall and may require ladder use. In big orchards, ladder use is not effective, and raised platforms attached to a tractor are used as an alternative (the same is applicable also in other fruit species born on taller trees and trees in hedgerow plantations).

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Also, mechanized harvest is possible with the use of machines combining people and automation for example Munckhof's Pluk-O-Trak harvester. The Pluk-O-Trak combines hydraulic platforms (which can be reconfigured for pruning, hand thinning, and trellis maintenance) with a series of conveyors that deliver apples to the bins. Pickers are working from the ground and platform and picked fruits are placed onto conveyors which deliver them to the bulk bin in the centre of the machine. There is less mechanical contact with fruits and less bruising which results in a quality increase of 50 – 60%. For industrial use (cider production) apples may be picked with a vacuum harvester which allows fruit picking from trees up to 3 – 4 m tall.

Fruit fallen onto soil may be gathered, placed into bulk bins and used for processing. It is sold for the lowest prices, however.

Research is performed to develop a machine vision system for automatic harvesting. However, it is a matter of the future.

14.4.2 Stone fruit

Similar methods as with pome fruit are used, however, fruits of this group are more soft and susceptible to bruising commonly and because of that picking to buckets is preferred and bins with a smaller capacity are used.

Thinning harvest is often used in stone fruit for dessert use because of gradual ripening, increased fruit quality and better price. The highest quality produce is picked by hand with gloves.

Self-picking is also used in these fruit crops and is increasingly popular in some countries.

For processing, stone fruits are harvested with shaking machines. 1 to 2 weeks before harvest term the trees are sprayed with Etephon or similar preparation (250 – 500 ppm Etephon concentration is used for cherries) which allows for uniform ripening and easier separation of the fruit from the stalk. Fruit is shaken onto a canvas spread under the trees and transferred into a bin or truck.

14.4.3 Berry fruit

Fruit for dessert use is often manually picked directly to containers (plastic, paper, veneer) in which fruit will be sold. Mechanized harvest is used in some countries for picking currants, blueberries, and raspberries for processing. Harvesting machines combine shacking with sucking off fruits separated from stalks. Anyhow, due to the gradual ripening of fruits using harvesting machines is limited because they cause yield quantity and quality loss.

Self-picking is increasingly popular in strawberry which is perishable fruit and this method shortens the way from farm to fork. Self-picking is possible in other berry fruit crops also.

14.4.4 Nut crops

The traditional way of nut harvesting is based on waiting until fruits drop from the tree naturally or knocking or shaking from trees (shrubs) with poles. Nuts can be shaken onto canvas or ground and then gathered into containers or baskets (small quantities), Walnuts fallen onto ground may be gathered also with the walnut picker – the cage-like tool which collects nuts while rolling along the ground.

In intensive commercial walnut orchards, nuts are removed from the trees using a mechanical shaker, a machine that grasps the trunk and shakes the whole tree. The nuts drop to the ground, are then swept into windrows and picked up with harvest machinery. This operation is completed quickly to reduce the time during which nuts remain on the ground. To increase the effectiveness of mechanised harvest

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Picture 82 Sorting machine for juicy fruits uses water for fruit conveying (Paulen)

14.5 Postharvest handling

Fruits (except nuts) must be cooled down up to the transportation or storage temperature (1 – 5 ^{o}C) as soon as possible after harvest to inhibit processes in the fruits that may cause quality loss. Different active methods of cooling are used – cooling tunnels (with a blast of cold air), containers with trash ice (not suitable for soft, perishable fruit) which may be used also for fruit transportation, etc. The traditional way of cooling – placing the fruit in a cool room or shaded place is not satisfactory for commercial technology. On the contrary, nuts are cleaned and dried immediately after harvest in drying facilities with warm air not exceeding the temperature of 35 ^{o}C.

Quick delivery to facilities for further processing (washing, grading, different conservation methods, packaging or storing) also diminishes quality loss. Cooling down of fruit may have the following benefits:

- inhibition of enzymatic degradation and lowering of respiration intensity, prevention of softening,
- slowing down water loss (shrivelling, wilting),
- slowing down microorganisms' expansion that causes fruit decay,
- reduction of ethylene generation or lowering fruit susceptibility to ethylene in “climacteric” fruits.

These bring higher flexibility concerning the market to get a better price for fruit and to supply the market continuously.

Fruits for immediate marketing or short-term storage are graded after harvest while fruits for long-term storage are preliminarily graded when harvesting to prevent unsound fruit from entering storage, and final grading is performed after taking fruits out of storage. Transportation machines must allow careful transportation with minimum fruit damage. Climatized trucks are essential if fruit should be transported to a distant place.

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Picture 83 Final sorting of walnuts aimed at excluding defective fruits (Paulen)

Picture 84 The procedure of apple fruits wrapping in cellulose bags during their development increases market value of fruits (Nováková)

14.6 Fruit storage

For the fruits with high content of water in the flesh, the period after harvest is crucial not only due to possible damage during fruit transportation and handling, but also due to infestation with pathogens causing fruit diseases, and due to postharvest ripening which leads to quality worsening and deterioration. The most important factors influencing storability are fruit species, cultivar, maturity stage at harvest and postharvest handling. With the use of up-

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to-date storage methods, also conditions within the storage chamber are important e.g. temperature, air relative humidity, the composition of the atmosphere in the storage chamber (CO_2, O_2, ethylene). The development in the field of storing technologies has been remarkable within the recent 30 years, however, still there are different types of storing facilities used. Their classification is as follows:

- Non-climatized storage rooms (cellars etc.) – to maintain fruit in a cool and humid atmosphere insulation ability of soil or other (building) materials is exploited and storage rooms are often sunken in the ground. This type of storage is old, primitive and does not need special technical equipment, however, the atmosphere in the storage room can´t be controlled substantially (only passive or active ventilation is used), the temperature in the store is very much depending on the external temperature. Storability in those conditions does not fit present requirements hence this storage type is used only by hobby, non-commercial fruit producers. Storage rooms of this type can be used for short-term cooling down and short storage immediately after harvest before shipping to customers.
- Storage facilities with cooled atmosphere – were built in the second half of the XX century. Storage technology was improved by the ability to control the temperature within the storage room. The rooms were insulated and it was no need to sink buildings in the ground. Due to the exploitation of cooling devices energy consumption was increased, storing period was extended and storing was possible also in a period when the external temperature was well above 0 ºC. This type also does not fit actual long term storage requirements.
- Storage facilities with controlled atmosphere (CA) – were launched in the last decade of the XX century. These are special facilities with perfect insulation (thermal, gasproof) of storage chambers in which several parameters are controlled – temperature, relative humidity, and composition of the atmosphere (CO_2, O_2, N, ethylene content). Decreased O_2 content in storing atmosphere while N and CO_2 contents are increased inhibits respiration, oxidation processes within the fruit and its ageing. Ageing processes are inhibited also due to ethylene removal from the storage atmosphere.
- Stores with ultra-low oxygen content in the atmosphere (ULO**)** – these are used actually for storing fruits for which an ideal O_2 content in the storage atmosphere is lower than 1 %. Similarly to the previous type also for this the perfect insulation of storage chambers is essential. Effects are similar to those of the previous storage type. The system enables the year-round storing of fruits (winter apples until new harvest).
- Special systems based on retardation of ripening process – results of research of fruit physiology are applied in practice. For example, SmartFresh™ is based on volatile substance 1-Methylcyclopropene which, when placed in storing chamber replaces ethylene with no ageing effect. Harvista™ contains also 1-Methylcyclopropene retards fruit ageing on tree and alows delayed harvesting of fruits at an optimum maturity.

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- Picture 85 ULO chamber for fruit storing (Paulen)

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