Czech University of Life Sciences Prague

Faculty of Forestry and Wood Sciences

Planting and Maintaining Trees in Cities - Course Study Guide

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Dear students,

This publication presents an introduction to the subject of Planting and Maintaining Trees in Cities. This first part is **dedicated to the environmental conditions** into which trees are planted. The goal is to familiarize with the range of problems that the urban environment creates and to adapt the selection of suitable tree species accordingly. Where possible, also consider potential site modifications or support measures that maximize the lifespan of the planted trees.

The text is written in regular font and italics. Interesting facts or information that complement the text or place the topic in context are written in italics. Subchapters conclude with a summary that serves as a quick overview of the topics covered in the chapter.

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CONTENT

Urban environments are characterized by specific conditions such as limited space for roots, compacted soil, limited water availability, high temperatures, and stress from surrounding infrastructure. Understanding these conditions allows for the appropriate selection of tree species and planting plans so that trees have enough space, access to water and nutrients, and can sustainably fulfill their expected ecological functions. We will progressively look at substances in the soil and the air that limit or directly harm tree growth and, if possible, at ways to minimize their harmful effects.

1. POLLUTANTS IN THE CITIES AND THEIR IMPACT ON TREES

Volatile organic compounds (VOCs) include all gases except carbon monoxide and carbon dioxide. They have a high vapor pressure at normal temperatures, meaning they evaporate easily into the air. In urban environments, they primarily originate from human activities and can significantly impact air quality and human health. Major VOC producers include automobile traffic (combustion of fossil fuels and additives), solvents, plastic manufacturing, and others. Examples of VOCs are benzene, toluene, xylenes, trichloroethane, benzaldehyde, and hexane. They also include polycyclic aromatic hydrocarbons (PAHs), organic compounds composed of several condensed aromatic rings. PAHs mainly form as byproducts of incomplete combustion of organic materials containing carbon (such as coal combustion, wood burning, coke, and asphalt production). The best-known PAH is benzo[a]pyrene.

Imissions have direct physical effects, such as particles clogging stomata, and also chemical effects as they penetrate the plant upon wetting, inducing toxic metabolic changes. This results in reduced photosynthesis, respiration, and transpiration, leading to visual symptoms like chlorosis and stunted plant growth. The chemical nature of these substances also causes changes in soil properties, including not only chemical composition but also microflora structure and nutrient cycling.

Sulphur and nitrogen oxides are produced during fossil fuel combustion and positively affect plants in small amounts, as they are macronutrients. If the plant can incorporate them into amino acids, it benefits from sulphur and nitrogen oxides. However, if emission levels exceed a certain threshold, the plant's internal environment acidifies due to the formation of weak acid solutions from the reaction of nitrogen and sulphur oxides with water, which harms the plant. Plants can buffer the negative effects of these oxides by taking up basic ions from the soil (e.g., calcium or magnesium ions). This response increases the concentration of the important tripeptide glutathione in the plant, which detoxifies the plant by binding xenobiotics with the help of the enzyme glutathione-S-transferase.

Glutathione is a tripeptide composed of cysteine, glutamic acid, and glycine. The cysteine residue contains a functional thiol group (-SH), which binds glutathione to xenobiotics and free oxygen radicals. It is thus an important antioxidant, functioning not only in plant cells but also in animal bodies. In humans, the highest concentration of glutathione is in the liver, and its deficiency can lead to accelerated aging of cells or neurodegenerative diseases.

The plant's response to increased SO_2 concentration includes an increase in zeaxanthin and a decrease in violaxanthin, key carotenoids in the xanthophyll cycle which involves the transformation of three carotenoids and accompanies deepoxidation, allowing the plant to dissipate excess energy from radiation as heat. Typically, glutathione concentration increases as an important antioxidant. SO_2 damages the cuticle and stomata, and upon penetration into internal tissues, can cause immediate cell death through plasmolysis or, more commonly, chronic damage accompanied by reduced assimilation rate due to chlorophyll degradation and altered cell permeability. Colour changes and later necrosis can be observed on leaves or needles.

SO_2 and NO_x emissions were reduced by tens of percent in the 1990s, but NO_x remains problematic, particularly in cities, due to increased automobile traffic and energy industries. Besides acidic deposition of nitrogen oxides, NO_x participates in photochemical reactions that produce tropospheric ozone, a component of photochemical smog. The EU has set the maximum NO_2 concentration at 40 $\mu g.m^{-3}$ as an annual average.

Until the 1920s, ammonia sources were limited. Industrial production was inefficient, and agriculture or military industry needs were mostly met by natural deposits of Chilean saltpeter (sodium nitrate $NaNO_3$). The Haber-Bosch synthesis, which combines hydrogen and nitrogen at very high pressure (15-25 MPa), temperatures (400-500 °C), and iron-based catalysts, enabled industrial ammonia production, for which Fritz Haber and Carl Bosch won the Nobel Prize in 1918.

Damage to plants from NO_x is usually chronic, involving a decrease in mesophyll pH, deamination of amino acids, and formation of toxic nitrosamines. Chlorosis and reduced growth are relatively nonspecific symptoms.

Air pollution, especially from nitrogen and sulphur oxides and heavy metals, was typical for Krušné hory region from the mid-1950s when coal power plants were built in Czechoslovakia, Poland, and Germany (the Black Triangle). Coal combustion with high sulphur content combined with extreme mountain climatic conditions led to forest ecosystem dieback over tens of thousands of hectares in the 1970s. Hourly concentrations exceeded permissible limits multiple times. Due to the dedication of generations of foresters, the forest was restored despite persistent *unfavourable conditions. Although the forest restoration using non-native species in Krušné hory is criticized today mainly regarding the spread of harmful introduced fungi or insects, the forest functions have been preserved up to now. A positive effect of sulphur emissions was their fungistatic effect on pathogenic fungi on the assimilation apparatus, whose increased presence became noticeable especially on spruce after the significant reduction of harmful air pollutants. Improvement of air quality thus brought this negative phenomenon.*

Since transport is associated with NO_x production, attention has shifted to NO_x emission reduction in this sector. Technologies used to reduce NO_x in exhaust gases include selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR). SNCR works by injecting ammonia or urea into the combustion chamber, which selectively reduce nitrogen oxides to elemental nitrogen and water vapor under reducing conditions. SCR uses modified engines equipped with a special catalyst where an aqueous urea solution (AdBlue) is injected into the exhaust pipe and chemically converted to ammonia in the presence of the catalyst, reacting with nitrogen oxides to convert them into harmless nitrogen and water.

Ozone is a triatomic oxygen molecule commonly found in the stratosphere. In the troposphere, it naturally forms from oxygen molecules split by UV radiation into oxygen radicals. The problem with ozone in cities is that a huge amount of ozone precursors like nitrogen oxides and VOCs (from natural or anthropogenic sources) form ground-level ozone under UV radiation. Temperatures above 30 °C also play a significant role in promoting ozone formation which is common in cities without vegetation during summer. Paradoxically, ozone concentration at higher altitudes often exceeds limits (the European limit is 120 $\mu g.m^{-3}$ as an 8hour average). Therefore, ozone concentrations in mountainous areas remain high throughout the day, while in cities ozone concentrations follow global radiation with a noon and afternoon peak and typically about one-third concentration at night. The gradient of ozone is reported as 60 $\mu g.m^{-3}$ per km up to 1000 m altitude, with high radiation also producing peroxyacetyl nitrate (PAN), H_2O_2, and aldehydes, all components of photochemical smog.

The exposure index AOT40 (accumulated exposure over 40 ppb, where ppb means parts per billion, i.e., 40 ozone molecules per billion air molecules) is commonly used in Europe to assess ozone risk to vegetation. It sums accumulated ozone amounts exceeding 40 nmol/mol each hour.

Typical ozone damage in plants appears as purple or black spots forming a granular mosaic on the sun-exposed leaf side. Spots are usually less than 1 mm, giving the leaf a “speckled” appearance. Shaded or adaxial leaf sides are typically free of these symptoms. Spots appear exclusively on the blade but not on veins. The "age effect" is characteristic, with damage notably affecting older leaves. Ozone-damaged trees have shortened growing seasons and prematurely shed leaves. Physiological changes under ozone influence include reduced photosynthesis rate and increased respiration, reduced growth, limited reproductive capacity, impaired epicuticular wax formation, and altered secondary metabolism pathways (phenylpropanoids, polyamines).

Trees absorb gaseous pollutants through stomata and leaf surfaces. Deposition rates depend on air movement in the canopy, transfer of substances from air to leaves, and stomatal conductance. It depends on current climatic conditions, crown shape, tree spacing, and tree physiology and morphology. Once gas diffuses into intercellular spaces, it reacts with water to form weak acid. Trees temporarily trap particulate matter with their canopy, but these particles are washed off by rain and fall to the ground. Some are absorbed and transformed inside leaves, with healthy trees able to remove significant amounts of gaseous pollutants, but leaf area is crucial. Besides vegetative season length, rainfall and other meteorological parameters also affect pollutant capture. For particulates, surface roughness is key, with trees having small, rough leaves covered with trichomes capturing more particles than trees with large, smooth leaves.

Under biotic or abiotic stress, plants produce reactive oxygen species as byproducts of metabolic reactions. Plants aim to eliminate these reactive oxygen species because they damage the plant, using enzymatic and non-enzymatic compounds (measured as enzymatic and non-enzymatic markers in lab practice). Their analysis helps determine plant stress and coping ability but these compounds are also produced during normal metabolic reactions, e.g., amino acid oxidation or the electron transport chain in respiration. Oxygen radicals have an unpaired electron seeking electrons from other molecules. The most known are oxygen radicals (ROS), but nitrogen radicals also exist.

Summary of the subsection:

- Emissions are substances released from a source, imissions are already present in the environment
- Volatile organic compounds are of anthropogenic and natural origin
- Plants respond to cell pH reduction by increasing uptake of basic ions from the soil
- Glutathione is an important antioxidant involved in the detoxification of oxygen radicals and toxic compounds

2. VOLATILE SUBSTANCES IN THE AIR OF ANTHROPOGENIC AND NATURAL ORIGIN

Although the positive impact of trees in urban environments is indisputable (reducing temperature through transpiration, capturing dust particles, detoxifying substances including SOx and NO_x), it is important to remember that trees (and plants in general) are a significant source of volatile organic compounds (Biogenic Volatile Organic Compounds, BVOC) and also pollen. BVOCs, sometimes also called NMVOCs (non-methane volatile organic compounds), are hydrocarbons that react with nitrogen oxides in the presence of ultraviolet radiation, contributing to the formation of tropospheric ozone, e.g. isoprene and monoterpenes (Sindelarova et al., 2022). VOCs released from plants react with hydroxyl radicals (OH·) forming oxidized products. These combine with NO to form NO_2. UV radiation cleaves oxygen radicals from NO_2, and atomic oxygen then combines with molecular oxygen to produce ozone. Trees emit BVOCs for protection against sunlight and oxidative stress, but also as a communication means between trees and insects. This amount is not negligible—it is usually estimated at 2–10 % of total fixed carbon. BVOC production significantly increases when the plant is stressed by high light or drought. Among trees commonly planted in our cities, plane trees, poplars, oaks, black locust, and lindens have the highest BVOC production. When selecting tree species, it is therefore necessary to consider their potential to produce pollen and BVOCs due to their significant impact on urban air quality. Trees also release a wide range of organic compounds that may be synthesized on the leaf surface due to UV radiation or directly emitted from tissues.

Summary:

- Trees are a significant source of volatile organic compounds (BVOC)
- Trees produce BVOCs as protection against sunlight
- BVOCs can react with nitrogen oxides to form ozone under UV radiation
- BVOC production increases if the tree is stresses

3. PARTICULATE MATTER

Particulate matter (PM) in cities mainly comes from emissions from traffic, household heating, and industry. PM includes carbon-based particles with hydrocarbons, acidic aerosols, or heavy metals (such as Cd, Mn, Cu, As, Sb) attached. These solid dust particles float in the air. They are named by their diameter in μm; for example, PM10 means particles with a diameter of 10 μm, which is a tenth of the thickness of a human hair. PM harms plants by covering the leaf surface used for photosynthesis and carries harmful substances like phytotoxic compounds or heavy metals that dissolve in water and enter the leaf through stomata. Benzopyrene, a toxic aromatic hydrocarbon made during incomplete burning of fossil fuels and somewhat during forest fires, is commonly found on PM2.5. The smallest PM2.5 particles are removed by trees, both by trapping them with leaves and physiologically. Deciduous trees are about eight times more effective at cleaning air than conifers. The removal of PM2.5 correlates with the plants' photosynthesis and carboxylation rates, probably because the particles enter leaves through stomata. Trees with high specific leaf area, like ginkgo, remove the most PM2.5. In addition to human-made particles, the air also contains biogenic particulate matter, mainly pollen. Pollen grains are the male reproductive cells, sized from a few to several tens of μm, and can travel long distances. Pollen irritates through proteins on its surface but can also bind harmful substances that increase its irritant effect. The biggest pollen producers include hornbeam, birch, hazel, and plane trees.

Summary of the subsection:

- Particulate matter (PM) refers to solid particles with diameters of several μm
- Plants are damaged mechanically by stomatal blockage and coverage of pigments
- PM often binds toxic substances, such as benzopyrene
- The removal of PM correlates with the rates of photosynthesis and carboxylation

4. SELECTION OF SUITABLE TREES FROM THE PERSPECTIVE OF BVOC PRODUCTION AND PM CAPTURE

Generally, coniferous trees are better at cleaning the air than deciduous trees, while deciduous trees are more effective at capturing particulate matter. Conifers, especially black pine, absorb more gaseous PAHs and are also able to clean the air in winter, when pollution is usually at its highest. The most efficient deciduous tree at capturing PAHs is birch, followed by black pine, while poplar (*Populus deltoides*) captures the least PAHs (Pleijel et al., 2022). According to another study, the best trees for capturing PM2.5 (calculated as grams of pollutants per tree per year) are *Acer truncatum*, *Robinia pseudoacacia*, and *Celtis burgeana* (Zhao et al., 2024). In general, trees with trichomes or a rough surface are recommended for capturing pollutants. Up to five times more pollutants are captured on the upper leaf surface than on the lower side. Surprisingly, the capture rate also increases with the number of stomata. Other structures positively correlated with the amount of pollutants captured include cuticular waxes, glandular trichomes, extrafloral nectaries, or structures producing viscous oil (*Acer truncatum*). While trichomes play the main role in capturing PM, the cuticle—especially its thickness and esterification capacity for translocation in leaf tissue—is the most important for capturing PAHs (Prigioniero et al., 2023)

The importance of trees in cities is undeniable. However, when planting trees, their arrangement and species must be considered on several levels. Trees close to each other that also form dense canopies promote the formation of ground-level ozone because reactive gaseous hydrocarbons have "more time" to react with BVOCs produced by the trees. The leaf surface and the solubility of pollutants play a large role; some pollutants likely become "encapsulated" and immobilized on the leaf surface (Grote et al., 2016). The uptake of harmful substances from the air partly depends on the isohydric and anisohydric strategies of plants during water shortage.

Anisohydric plants are aptly called "risk-taking plants" in English literature. While isohydric plants maintain a constant midday water potential regardless of whether it is dry or water is sufficient, the water potential of anisohydric plants fluctuates according to water availability. Both strategies have their advantages. During periods of mild water stress, anisohydric plants benefit, while during severe stress, isohydric plants may have the advantage. Anisohydric plants have high resistance to cavitation, and their zero assimilation point (that is, the moment when CO_2 uptake balances its release, in English called the zero assimilation point) corresponds—for example, in juniper—to about ψ = -4.2 MPa, whereas in pine, which did not survive *months of drought, the zero assimilation value is approximately at water potential ψ = -2.0 MPa (Breshears et al., 2008).*

Anisohydric plants are more effective at removing airborne pollutants because their stomata remain open even during less favorable climatic conditions. From this perspective, it is more suitable to consider planting more poplars and oaks in cities rather than plane trees or pines, as O_3 or NO_x are immediately metabolized in the apoplast of their leaves. On the other hand, it must be borne in mind that no universal tree exists that removes large amounts of airborne pollutants, produces no BVOCs or pollen, and is also drought-tolerant. For example, Tilia cordata has zero ozone formation potential (the so-called OFP, ozone formation potential), but compared to spruce, it captures only a fraction of both particulate matter and airborne pollutants. Spruce, however, has a very high OFP. For our conditions, considering the above criteria, beech appears to be one of the optimal tree species, having high water use efficiency (expressed in mg CO_2/g H_2O), high shading capacity, a moderate potential for removing PM, and a medium to low emission potential and allergenic potential of its pollen (Grote et al., 2016).

Summary of the subsection:

- Coniferous trees clean PAHs from the air better than deciduous trees and also function in winter, when pollution is worst
- Deciduous trees are more effective in capturing particulate matter
- Rough leaf surfaces and the number of stomata increase pollutant capture
- The cuticle is key for capturing and detoxifying polyaromatic hydrocarbons

5. CARBON DIOXIDE

Carbon dioxide is one of the compounds enhancing the greenhouse effect. Although the direct impact of CO_2 on plants is positive, as it is a key gas in photosynthesis, its indirect negative influence is clearly harmful. Besides the well-known physiological consequence of higher CO_2 concentrations in the form of increased photosynthesis rates, higher CO_2 also promotes better water use because stomata can be less open when CO_2 is abundant. The usual strategy of trees growing in elevated CO_2 conditions is the temporary redirection of carbon sinks into root biomass. This increases the tree's ability to obtain more water and nutrients from the soil. However, physiological traits leading to greater prosperity can easily turn disadvantageous under unfavourable conditions: greater aboveground biomass means larger leaf area and thus higher transpiration demand. Since the CO_2 increase is not compensated by a corresponding increase in soil nutrients, more biomass is created with the same nutrient availability. The wood of such trees contains significantly more carbon compounds than nitrogen compounds, which affects not only the chemical properties of the wood but also consumption by herbivorous insects and the overall content of defense compounds. Moreover, a higher amount of carbohydrates in the photosynthetic apparatus attracts sap-feeding insects. Into this scenario come climate changes caused by CO_2 concentration and other greenhouse gases.

The greenhouse effect principle lies in heating the Earth's surface, which re-emits thermal radiation, part of which is reflected back by the greenhouse gas layer, causing additional warming. This phenomenon was described and surprisingly precisely quantified in the 19th century by Svante Arrhenius, who predicted planetary warming due to human activity. The term "greenhouse effect" is misleading and unrelated to a greenhouse's actual principle. In a greenhouse, air heats due to limited air movement in a small space, not because of greenhouse gases. Besides CO_2*, water vapor, methane, nitrous oxide (N2O), and hydrofluorocarbons (currently restricted but with long atmospheric lifespans) also reflect long-wave radiation.* CO_2 *thus raises temperatures, increasing transpiration demands and reducing soil water. Higher* CO_2 *concentrations associate with weather extremes and warming. There is a risk of habitat loss for long-lived trees that cannot adapt quickly enough. Climate change also significantly alters phenology—the timing of seasonal events—affecting trophic relationships, for example, between insects and birds. A study by Botha et al. (2006) reported that 90% of the pied flycatcher population in the Netherlands died because the peak of caterpillar populations, the main food for the chicks, occurred before the adult birds arrived from wintering grounds.*

Through photosynthesis, trees contribute globally to reducing CO_2 concentrations over a year, with this reduction reaching 1–2 % during the growing season in the Northern Hemisphere.

Summary of the subsection:

- Carbon dioxide is essential for photosynthesis and increases plant growth and water use efficiency due to partial stomatal closure
- Elevated CO_2 stimulates root system growth, improving water and nutrient uptake
- Positive effects of CO_2 are offset by consequences of increased atmospheric CO_2, especially higher evapotranspiration demands
- Plants contribute to global CO_2 reduction by 1–2% during the growing season in the Northern Hemisphere

6. HEAVY METALS IN THE SOIL

Heavy metals such as cadmium, lead, chromium, mercury, and aluminium (which, although a light metal, has effects on plants similar to heavy metals) are considered toxic elements for plants. The toxicity of these metals lies in their negative effects at various levels. They inhibit the function of guard cells in stomata, disrupting water regulation and photosynthesis in plants. They also inactivate enzymes by occupying binding sites for other elements and disturb ATPase function. Additionally, through the generation of reactive oxygen species via the Fenton reaction, they increase oxidative stress in tissues. Plant sensitivity to these toxic elements varies significantly—conifers can tolerate hundreds of micrograms of aluminium per gram of dry weight, while most plants do not need aluminium at all. Toxicity of some metals arises from their similarity to essential elements, allowing them to replace metal cofactors in many metalloproteins, usually resulting in nonfunctional molecules. Toxic metals also damage enzymes by binding to the SH groups of amino acids like cysteine and methionine. Furthermore, they disrupt membranes and cause imbalances in cellular redox processes. Particularly dangerous is the ability of iron and copper ions to catalyze the formation of highly reactive hydroxyl radicals from hydrogen peroxide under certain conditions. The Fenton reaction is a chemical process where hydrogen peroxide (H_2O_2) decomposes in the presence of ferrous ions (Fe^{2+}) to form highly reactive and toxic hydroxyl radicals (·OH).

The principle is that Fe^{2+} acts as a catalyst, breaking hydrogen peroxide into hydroxyl radicals and hydroxide ions (OH–), while itself being oxidized to Fe^{3+}. This reaction proceeds best at acidic pH around 2.8–3, and the generation of hydroxyl radicals leads to strong oxidative effects that can damage cellular structures, such *as increasing oxidative stress in plant tissues. This mechanism is also significant in biological and environmental processes, where generated hydroxyl radicals react with organic substances, causing their breakdown or damaging cellular components.*

Trees defend against oxidative stress using a complex antioxidant system divided into enzymatic and non-enzymatic antioxidants. Enzymatic antioxidants include key enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). SOD is a metal-containing enzyme (iron, zinc, copper) that performs the crucial first step—removing superoxide radicals by converting them into oxygen and hydrogen peroxide. Hydrogen peroxide is then broken down by other enzymes, mainly catalase, which decomposes it into water and oxygen, preventing cellular damage. This enzymatic system is essential for preventing damage caused by lipid peroxidation, which can be monitored by markers like malondialdehyde (MDA) and indicators such as electrolyte leakage from cells. Most plant antioxidants are hydrophilic (SOD, CAT, phenolics, flavonoids, ascorbic acid), while hydrophobic antioxidants are part of membranes, including carotenoids, tocopherols, and ubiquinones. In addition to enzymatic antioxidants, non-enzymatic antioxidants like glutathione (GSH), proline, phenolic compounds, and combinations of glutathione and ascorbate play important roles. These substances contribute to detoxifying reactive oxygen species by direct neutralization and complement the plant's protective system, especially under stress conditions. Glutathione also plays a role in heavy metal protection and is a precursor to other detoxifying enzymes. The overall plant defense system enables not only the removal of harmful oxidative substances such as H_2O_2 and superoxide radicals but also maintains membrane stability and enzyme functionality under challenging conditions.

Besides heavy metals, soils and waters in urban environments can contain substances whose use has been banned for decades. These are persistent chemicals, often with bioaccumulative properties. They hardly degrade in nature and accumulate in animal tissues. Examples include polychlorinated biphenyls used as transformer fluids, polybrominated biphenyls (PBB), and polybrominated diphenyl ethers (PBDE) used as flame retardants. Burning chlorinated polymers releases polychlorinated dibenzodioxins and furans (PCDDs and PCDFs), commonly known as dioxins. The group also includes organochlorine pesticides such as DDT, polycyclic aromatic hydrocarbons (PAHs), and brominated flame retardants.

Summary of the chapter

- Heavy metals such as cadmium, lead, chromium, mercury, and aluminium are toxic to plants and disrupt the function of stomatal cells, affecting water regulation and photosynthesis
- These metals inactivate enzymes and disrupt ATPase function, while increasing oxidative stress by generating reactive oxygen species (Fenton reaction)
- Plant sensitivity to toxic metals varies, and some metals replace essential metal cofactors, creating nonfunctional molecules
- Metals damage enzymes by binding to thiol groups of amino acids, disrupt membranes, and catalyze the formation of highly reactive hydroxyl radicals

7. OXYGEN SHORTAGE IN THE SOIL

In plants, cellular respiration is a process in which energy from broken-down organic compounds is converted into a form usable by the cells, mainly ATP molecules. During this controlled breakdown, substrates are oxidized at normal temperatures, enabling efficient energy use in plant metabolism. Enzymes in plant cells help overcome energy barriers and divide the process into multiple steps, allowing plants to save energy and easily regulate its consumption. Plant respiration not only supplies energy but also provides important carbon components used to form lipids, nucleic acids, and proteins. When energy production is not needed, plants reduce respiration efficiency and instead release more heat. Rapid respiration in spring flowers raises temperature and accelerates the maturation of reproductive cells. Heating tissues with waste heat may also promote the release of volatile compounds that attract pollinators or enemies of pests. Oxygen can thus also diffuse through the cuticle of leaves, bark, and other surfaces. Additional oxygen enters through lenticels on stems and roots with root hairs, where oxygen comes from both soil air and soil solution. Moreover, photosynthetic organs utilize oxygen generated directly by water splitting in photosynthesis. The problem of oxygen deficiency in urban soils lies in the different diffusion to roots compared to leaves. While air with only a few percent oxygen does not significantly affect leaf metabolism, young roots are affected when oxygen drops below 20%, a level corresponding to well-aerated soil but only in surface layers. Older roots are less sensitive to oxygen content, mainly due to their low respiration rate. Plant respiration occurs simultaneously with photosynthesis, but during intense photosynthesis, it is usually significantly suppressed. If there is enough oxygen in the wood, the glycolysis product—pyruvate in the form of acetyl CoA—enters the Krebs cycle, which is followed by the electron transport chain. Within this system, ATP molecules are produced and serve as energy for other physiological processes. If oxygen is scarce, fermentation follows glycolysis. This takes the form of either alcoholic or lactic acid fermentation, products of which are ethanol or lactic acid.

When oxygen is lacking, reduced NADH accumulates, produced during glycolysis. Fermentation allows its reoxidation to NAD^+, which is necessary for glycolysis to continue and thus for the cell to gain energy without oxygen. In alcoholic fermentation, pyruvate undergoes decarboxylation to acetaldehyde, which is then reduced to ethanol. In lactic acid fermentation, pyruvate is directly reduced to three-carbon lactate. In plants, both fermentation types can occur simultaneously or sequentially, helping maintain energy metabolism under anaerobic conditions.

Hypoxic conditions are common in cities, and most plants can obtain energy through fermentation. Soil compaction can be measured using a penetrometer. The penetrometer principle for measuring soil compaction involves vertically pressing a conical or cylindrical tip into the soil and recording the force or resistance posed by the soil. This resistance is proportional to soil compaction—the more compacted the soil, the greater the resistance and the more force is needed for the tip to penetrate deeper. The value measured by the penetrometer provides information not only on compaction but also on the soil's water retention capacity and the limitation of biological activity. Fermentation does not directly harm the tree but leads to a low energy yield from respiration. Since respiration is continuous, it is a determining factor of the tree's overall carbon balance. This is especially true for trees where living but non-photosynthetic biomass dominates over time. Respiration is necessary not only for growth but also for protein synthesis and defensive processes, including the synthesis of secondary metabolites that protect the plant from adverse conditions and pests.

Summary of the subsection:

- Cellular respiration in plants converts energy from organic compounds into ATP, the main energy source
- When oxygen is scarce, plants use an alternative energy-producing process called fermentation
- This process reduces energy yield but does not directly damage the tree; respiration remains essential for growth, protein synthesis, and defense responses

8. OPTIONS FOR THE SOIL ENVIRONMENT IMPROVING

Urban soils often suffer from mechanical compaction which further reduce soil permeability for air and water. The hydric conditions of these soils are also specific. Usually, there is a lack of water in the soil profile, but the opposite can occur, with a raised groundwater level. This condition causes waterlogged roots to start rotting, leading to crown drying and significant weakening of tree vitality. Soil compaction can be addressed using an injector that injects air under pressure, creating cavities which, besides aeration and altering soil structure, promote root growth. Along with injection, superabsorbents or site-supporting substances can be introduced into the soil. Substances that can be injected this way include mycorrhiza, vermicompost, or zeolite. When selecting mycorrhiza, the tree species must be considered. Trees like maple, ash, rowan, and fruit trees primarily form endomycorrhiza, where fungal hyphae penetrate directly into the primary cortex cells of the root and form tree--like structures called arbuscules, which increase the contact area for nutrient and water exchange. Conifers are typical for ectomycorrhiza, where fungi cover roots with a dense hyphal layer but do not penetrate cells; instead, they form the so--called Hartig net around roots. The ideal pH for most mycorrhizae is approximately between 4.7 and 4.9, a slightly acidic environment in which fungi best thrive and form symbiosis with plant roots. In slightly alkaline substrates, often typical of urban environments, mycorrhiza can also function but at a slower rate and with lower effectiveness on the plant. Comparing nutrient transport speeds among mycorrhiza types shows that endomycorrhiza has rapid transport because its mycelium lacks septa, enabling efficient nutrient and water transfer. Regarding soil physical properties, ideal soils are loamy sand or sandy loam with low groundwater levels and relatively low nutrient content, as such environments best support mycorrhizal fungi development.

Soils can also be improved by adding vermicompost. Vermicompost is an organic fertilizer produced by the decomposition of biological waste by earthworms and microorganisms. This type of compost is highly microbiologically active, containing numerous beneficial bacteria, fungi, and actinomycetes that improve soil quality and support plant vitality. Vermicompost is rich in humic substances, enzymes, and natural growth hormones such as auxins, gibberellins, and cytokinins; it increases microbial activity in soil and promotes organic matter decomposition and nutrient availability. Consequently, plants absorb water and nutrients better, become more resistant to diseases and pests, and soil structure and its water retention capacity improve. Zeolite and Terramol are natural materials that enhance soil structure and its ability to retain water and nutrients. Zeolite enriches soil with nutrients, retains water which it subsequently releases to trees, and improves aeration. Water retention in soil is also supported by superabsorbents. Growth stimulators called PGPR (Plant Growth Promoting Rhizobacteria) can also be used. PGPR can produce organic acids, which break down poorly available phosphorus into soluble forms, increasing its availability to plants. Additionally, they produce various phytohormones, such as auxins, which support root system growth. Overall, they increase microbial activity and improve the physical properties of soil in the rhizosphere.

Summary of the subsection:

- Urban soils are compacted, oxygen levels are low, and the soil has insufficient water retention capacity
- besides aeration, soil properties can be improved by adding superabsorbents, mycorrhiza, vermicompost, and zeolite
- Mycorrhiza helps increase water and nutrient uptake but is less effective in alkaline urban soils
- Vermicompost and zeolite support microbial activity, water and nutrient retention, improving plant growth and vitality

9. HIGH TEMPERATURES AND HIGH IRRADIANCE

Optimal photosynthesis temperatures range between 20 - 35 °C. If temperatures are higher, transpiration increases to cool the photosynthetic apparatus, provided there is sufficient water in the soil profile. Photosynthesis decreases faster at excessively high temperatures due to damage to the photosynthetic apparatus than it does at low temperatures. Therefore, long-term elevated temperatures do not threaten trees primarily due to overheating, but combined with water shortage, which often accompanies high temperatures, there is a risk of excessive loss of carbon compounds needed for cell regeneration, metabolic processes, and defense.

The urban heat island phenomenon is caused by the high accumulation of materials like asphalt and concrete, which significantly absorb heat from solar radiation and have lower heat reflectance. Large asphalt areas also prevent rainwater infiltration, causing faster runoff. This leads to lower air humidity compared to, for example, grassy ecosystems. The heat island effect is most pronounced at night and during clear, windless weather, when materials gradually release accumulated heat. This results in temperature differences of several degrees Celsius compared to the surrounding environment.

Since biomembranes have a semi-fluid character that changes to a fluid state at high temperatures, elevated temperatures mainly affect the transport functions of proteins and membrane carriers, including membranes inside the cells. Above 40 °C, the cytoskeleton breaks down, cytoplasmic cyclosis stops, and substance distribution within the cell ceases. Plants defend themselves effectively by increasing saturated fatty acid content, which remain solid even at high temperatures. Saturated fatty acids are more thermally stable than unsaturated ones because they lack double bonds, which are prone to oxidation and degradation at high temperatures. Cells also increase heat shock proteins, which protect existing proteins, and proteases, which break down damaged proteins.

For photosynthesis to proceed, trees require photosynthetically active radiation. If light is excessive, photosynthetic capacity is saturated, and additional light is converted largely to heat waste. This is accompanied by the formation of reactive oxygen species, especially singlet oxygen in photosystems and superoxide in the electron transport chain. Trees protect themselves from excess light by producing substances like flavonoids, antioxidants (especially carotenoids), and creating barriers such as the cuticle or lignin.

Flavonoids in plants absorb UV radiation at different wavelengths, 320–400 nm, and the more harmful UV-B range of 280–320 nm. They prevent DNA damage and reduce oxidative stress caused by reactive oxygen species. They also have antioxidant properties and, in entomogamous species, facilitate interactions with pollinators through colourful petals. Flavonoid synthesis increases in leaves in response to elevated UV radiation.

Summary of the subsection:

- At temperatures above 30 °C, respiration predominates, causing the plant to lose carbon, and long-term high temperatures combined with water shortage damage cells
- High temperatures disrupt membrane functions and the cytoskeleton; the plant defends itself by increasing saturated fatty acids and stress proteins
- Excess light leads to the formation of reactive oxygen species; plants protect themselves with flavonoids, carotenoids, cuticle, and lignin

10. DROUGHT

Drought significantly affects urban trees mainly by severely limiting soil water availability, which trees draw upon for growth and physiological processes. Transpiration, or water evaporation from leaves, depends on stomatal openness and surrounding physical conditions such as low relative humidity, high light intensity, and temperature, which increase the vapor pressure deficit and thereby water loss from plants. In urban environments, limited water intake is often caused not only by low soil moisture but also by high salt concentrations in the soil and low temperatures, which reduce root metabolic activity.

During prolonged drought, trees' ability to absorb water decreases, possibly leading to plasmolysis of root cells and irreversible damage. When soil water potential falls below approximately -1.5 MPa, most plants can no longer efficiently take up water, marking the permanent wilting point. Drought stress is often linked with another urban factor—soil salinization—that hinders water uptake and exacerbates water deficiency in plants. Water shortage leads to stomatal closure, reducing transpiration cooling of leaves, which at high temperatures causes a rapid rise in leaf surface temperature and increases the risk of heat damage to plants.

At the molecular level, trees respond to drought stress by activating specific proteins, such as LEA proteins and dehydrins, which protect biomembrane structures and other proteins from damage caused by water deficiency. Dehydrins also act as antioxidants and bind metal ions, thereby reducing harmful reactive oxygen species formation and protecting cells from damage.

There are several ways to improve water availability for urban trees. Besides irrigation bags and watering basins at planting sites, it is beneficial to allow tree roots to connect with nearby green areas. Perforated blocks creating a "bridge" between roots and green space are successfully used abroad. Rainwater is increasingly utilized, washing away de-icing salts and providing water for plantings near roads. The amount of water a tree consumes depends on its leaf area size, with young plantings requiring tens of liters weekly for cooling.

Summary of the subsection:

- Transpiration increases with low humidity and high temperatures, but soil water is often unavailable due to salinization and low temperatures
- Water deficiency causes stomatal closure, limiting leaf cooling and increasing the risk of overheating and damage
- Trees activate stress proteins that protect cellular structures and reduce oxidative stress

11. SOIL SALINIZATION

Salts in cities are primarily used in winter to ensure safety and maintain road usability during frosty days. De-icing salts, most commonly sodium chloride (NaCl) and calcium chloride (CaCl2), lower the freezing point of water, prevent ice formation, and dissolve existing frost or snow. An alternative to salts, which would address the high costs and negative impact on urban greenery, is gravel. Gravel reduces the risk of accidents but does not affect the freezing point.

The difference between de-icing salts lies mainly in their effectiveness and temperature range of use. NaCl is the most common and economically affordable salt that effectively melts ice and snow at temperatures around –7 to –9 °C but becomes less effective at lower temperatures, requiring larger amounts to achieve the same effect. In contrast, CaCl2 is effective even at temperatures down to about –29 °C; calcium helps stabilize soil structure and reduces the harmful effects of sodium, making it gentler on trees. However, its use is more expensive.

Excessive soil salt levels cause osmotic stress in trees, lowering water potential and making water less available to roots. If soil salt concentrations, such as sodium and chlorides, are too high, plants cannot absorb adequate water, leading to growth slowdown, bud development inhibition, and even death.

Tree responses to salinity also manifest in physiological functions. For example, during short-term salt exposure, transpiration slows as the plant closes stomata to minimize water loss. However, this reduced transpiration limits leaf cooling under sunny conditions, causing leaf temperatures to rise by several degrees. Long-term high salt concentrations significantly slow photosynthesis and biosynthetic processes, especially in sensitive species. This results in reduced shoot growth, inhibited bud development, and decreased photosynthetic activity. External damage signs include leaf browning and reduced resistance to environmental stresses. Root hairs responsible for water and mineral uptake are damaged; damaged root hairs disappear or are severely shortened, significantly reducing the plant's water absorption capacity. At the cell wall and membrane levels, adaptive mechanisms enable plant survival in saline environments. These include the production of dehydrins, which protect the structural integrity of proteins and membranes, and active ion transport, whereby plants pump out excess Na^+ ions or sequester them in vacuoles, reducing toxic cytoplasmic concentrations.

Salts also affect soil physical parameters, causing swelling and shrinking of soil particles, leading to compaction and reduced porosity and water permeability.

Additionally, soil often becomes alkaline, which limits the availability of certain essential nutrients and restricts plant nutrition.

Willows and some poplar species are very sensitive to salt presence. Most of our tree species show moderate tolerance to saline soils. Conversely, highly tolerant species include introduced ones such as black locust (*Robinia pseudacacia*) and conifers like pine and juniper.

Soil dissolved salt concentration can be determined by measuring electrical conductivity. This process involves mixing a soil sample with distilled water, followed by centrifugation and measuring the extract's conductivity with a conductometer. The result is expressed in units of $mS.cm^{-1}$ or $\mu S.cm^{-1}$, with a typical optimal soil conductivity value for most soils up to 0.7 mS/cm. Values exceeding 1.2 $mS.cm^{-1}$ indicate excessive soil salinity, requiring selection of salt-tolerant tree species.

Summary of the subsection:

- Excessive soil salt causes osmotic stress, limits water uptake, and damages tree growth and development
- Salts induce osmotic stress within the plant
- Pines and junipers are salt-tolerant, whereas willows and poplars are sensitive

12. SOIL REACTION AND OTHER SOIL PARAMETERS

Soil pH in cities ranges from 6 to 8. The slightly alkaline reaction is caused by the use of de-icing salts in the winter and the presence of calcium compounds. A slightly acidic soil reaction can be locally caused by increased concentrations of dog urine. Increased soil alkalinity causes the decomposition of colloidal particles in the soil and their transformation from a solid phase into a stable colloidal solution, known as peptization of soil colloids. As a result of peptization, soil conditions for plant growth worsen because the breakdown of soil aggregates significantly reduces water and nutrient availability. The uptake of some nutrients, especially micronutrients, is limited. Another characteristic of urban soils is marked stratification, with layers differing in physical and chemical properties, complicating uniform water and nutrient uptake.

Soil reaction is determined as active acidity (pH/H_2O) caused by hydrogen ions in the solution or as exchangeable acidity (pH/KCl), which is due to hydrogen ions displaceable from the sorption complex. Measurement in H_2O provides a more general view of soil acidity, while the pH value in KCl better reflects the soil's nutrient-holding capacity and is a more accurate indicator of nutrient availability for plants. At pH values significantly above 7, the uptake of trace elements such as manganese and iron is blocked. There is no optimal pH for trees, as each species has different requirements. For example, walnut requires neutral soil, while conifers prefer slightly acidic soil.

Due to the frequent presence of construction rubble in urban soils, the presence of calcium carbonate in soil can be roughly assessed using 10% hydrochloric acid. The reaction of HCl and $CaCO_3$ causes effervescence due to the release of carbon dioxide. The intensity of effervescence corresponds to the carbonate content in the soil: very weak effervescence suggests less than 0.3 % carbonates, while strong and sustained effervescence indicates carbonate contents above 2 %.

Summary of the subsection:

- Urban soils are usually slightly alkaline due to de-icing salts and calcium compounds
- Soil stratification in cities complicates uniform water and nutrient uptake
- Soil pH affects nutrient availability; at pH above 7, micronutrient uptake is limited

13. PESTICIDES, THEIR OCCURRENCE IN THE ENVIRONMENT AND IMPACT ON PLANTS

Pesticides are substances most commonly used to control plant diseases, eliminate weeds and animal pests, and protect plants and stored crops. The active ingredients in pesticides have changed over time depending on technological developments, agricultural needs, and legislative restrictions.

The use of pesticides dates back to ancient times. One of the oldest agents used to combat plant diseases was sulphur, known even before 1000 BCE. In 79 CE, Pliny recommended arsenic as an insecticide. The 17th century saw the first use of a naturally occurring insecticidal substance found in tobacco plants (*Nicotiana tabacum*) — nicotine. In the 18th century, mercuric chloride was used to protect wood.

Arsenic is an outdated term for arsenious oxide and was a popular poison in the Middle Ages. Death from arsenic poisoning was often mistaken for diseases with similar symptoms, such as cholera. A definitive test for arsenic poisoning was the Marsh test, invented in 1832. The test involves reacting zinc shavings with sulfuric acid. When stomach contents suspected of containing arsenic are added, the hydrogen produced from Zn and H_2SO_4 reacts with arsenic, producing arsine gas that decomposes upon heating to deposit metallic arsenic on a ceramic dish. Due to continued misuse, the Arsenic Act of 1851 was enacted in the UK, introducing regulations such as poison sale registration and daily sales limits.

In the mid-19th century, two natural insecticides were discovered: rotenone from the roots of the leather vine (*Derris elliptica*) and pyrethrum from chrysanthemum flowers. Bordeaux mixture, composed of lime and copper sulphate, became a significant agent suppressing fungal pathogens; it forms copper hydroxide in water, an effective antifungal. Despite its natural origin, repeated use requires consideration of copper accumulation in soil.

Synthetic organic pesticides surged in the 1930s. The best-known herbicides from that era are organochlorines, including dichlorodiphenyltrichloroethane (DDT), developed in 1939. Like many pesticides, DDT is persistent and an endocrine disruptor, accumulating in the environment and disrupting hormonal balance in animals. Carbamate esters, derivates of carbamic acid, form another important group. Phenoxyacetic acids gained popularity as herbicides a few years later; they are transported through the plant's vascular system and suppress dicotyledonous plant growth. They also naturally occur in much lower doses as parts of phytohormones like auxin.

The American marine biologist Rachel Carson first highlighted the environmental problems caused by pesticides in her book "Silent Spring". She documented and demonstrated the link between DDT use and declined bird populations due to direct poisoning or eggshell thinning, which prevented chick hatching. She also pointed out connections between pesticide use and human cancer, verified experimentally on lab animals, and presciently predicted pesticide persistence and invasive pathogen introduction to weakened ecosystems. In Czechoslovakia, DDT was banned in 1974, but limited controlled use continues worldwide due to its effectiveness against malaria vectors like Anopheles mosquitoes.

The 1970s marked a breakthrough with glyphosate (Roundup), which inhibits the shikimate pathway, preventing the production of aromatic amino acids. Its metabolite is aminomethylphosphonic acid (AMPA). Blocking this pathway stops amino acid synthesis, leading to plant death. Glyphosate is transported through vascular tissues, making it effective only when applied to green plant parts. Its use is now heavily restricted due to probable negative health effects.

Insecticides target essential biological processes in insects, causing malfunction or death. Many of them are based on blocking acetylcholinesterase, the enzyme that breaks down acetylcholine—a neurotransmitter in synapses. If acetylcholine accumulates, synapses become permanently stimulated, leading to paralysis; carbofuran is a typical example. Pyrethrins and synthetic pyrethroids disrupt electrical signals by affecting hydrogen channel permeability, causing nerve paralysis. Some insecticides block electron transfer from complex I to ubiquinone in mitochondria, preventing ATP synthesis; rotenone is in this group. Some inhibit chitin synthesis, crucial for insect exoskeletons. Another group contains insect hormone analogs (ecdysteroids) that prevent developmental completion.

Herbicides affect plant metabolism by inhibiting aromatic amino acid synthesis (glyphosate), lipid-synthesizing enzymes, or photosynthesis by blocking electron transfer or inducing reactive oxygen species production. Some herbicides inhibit DNA replication or RNA synthesis, arresting cell division and plant growth. Synthetic plant hormones can be applied in much higher doses than naturally occurring, causing uncontrolled growth leading to death (e.g., 2,4-dichlorophenoxyacetic acid). Others block protein, carotenoid, or cellulose formation (Cremlyn, 1985).

Beyond synthetic pesticides, naturally occurring plant-produced pesticides exist as an evolutionary outcome of millions of years of plant and pest interactions, primarily insects. All plants produce various secondary metabolites repelling or killing attackers. Practically useful natural pesticides include nicotine (*Nicotiana tabacum*), rotenone (found also in *Verbascum densiflorum*), and pyrethrins. Synthetic pyrethroids, derived from pyrethrins isolated from the Dalmatian chrysanthemum (*Chrysanthemum cinerariaefolium*), remain in use as ecological measures against crawling and flying insects, including in residential areas. They exhibit low toxicity to mammals due to rapid hydrolysis but have limited stability due to fast photodegradation. Pyrethroids have largely replaced earlier organophosphates.

Neem oil, derived from the South Asian neem tree (*Azadirachta indica*), acts as an insecticide with additional bactericidal and fungicidal effects. Phytoecdysteroids, initially discovered in insects as steroidal hormones regulating molting, act in plants as secondary metabolites and hormonal disruptors, controlling insect development.

Summary of the subsection:

- Pesticides are used to suppress plant diseases, weeds, and pests, with active ingredients evolving alongside technology and legislation
- Historically, substances like sulphur, arsenic, nicotine, and mercuric chloride were used, with synthetic pesticides such as DDT and glyphosate developing in the 20th century
- Insecticides act on the insect nervous system by blocking enzymes or disrupting electrical signal transmission
- Natural plant-derived pesticides also exist, with lower toxicity to mammals

14. POLLUTANTS MONITORING IN THE ENVIRONMENT

The most significant pollutants include solid particles, ammonia, sulphur and nitrogen oxides, and non-methane organic compounds. Besides the well-known pollutants, organic substances that often persist in the environment in unchanged forms, are transported over long distances, accumulate in the environment or animal tissues, and have cumulative effects are also present.

The Stockholm Convention, signed in 2001, regulates persistent organic pollutants (POPs), classifying substances according to danger into a) substances that must be eliminated from production and b) substances with restricted use. The Czech Republic has ratified the convention and fulfils its obligations through National Implementation Plans. The EU aims, for example, to remove perfluorinated compounds, which practically do not degrade in the environment.

The European Chemicals Agency (ECHA) also participates in the control of substances in the environment. The inclusion of substances on the list of potential very high concern substances (SVHC) is decided by the European directive on the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH). The European Environment Agency (EEA) addresses knowledge regarding the environment, climate, and sustainability.

Summary of the subsection:

- The Stockholm Convention is an international agreement from 2001 that legally binds countries to restrict the production, use, and release of selected persistent organic pollutants
- The European Chemicals Agency (ECHA) participates in monitoring substances in the environment

15. LIGHT POLLUTION

Light pollution is defined as light that alters the natural cycles of light and darkness in an ecosystem (Czaja and Kołton, 2022). It is therefore not a physically defined term or a pollutant in the strict sense of the word. It is the scattering of artificial and human-made light reflected by particles in the air. Even on a moonless night, the illuminance could be measured, while under moonlight, it can reach up to 1 lux (Singhal et al., 2019). Light, as the main physical environmental factor, affects plants from germination through pigment formation to flowering—all included in the concept of morphogenesis. Light pollution can accelerate leaf development by up to 20 days under nocturnal illumination of 30 $\mu mol.m^{-2}.s^{-1}$ and significantly reduces soluble sugar levels (Czaja and Kołton, 2022). It also affects flowering and leaf abscission, which prolongs under light influence, possibly impacting their ability to endure dormancy due to depletion of storage compounds.

Singhal et al. (2019) summarize physiological changes caused by nocturnal lighting:

- Effect on light receptors Pr/Pfr. Changes in their ratio either induce or inhibit flowering.
- Disruption of circadian rhythm
- Oxidative stress, UV radiation stress, DNA damage, wilting due to high night temperatures and elevated vapor pressure deficit, and balancing of day and night temperatures
- Reduced assimilation rate, quantum yield, and changes in PSII activity. Leaves show lower chlorophyll concentration and less nitrogen
- Plants may suffer carbon deficiency due to presumed higher demands for maintaining high respiration rates

Light pollution dramatically impacts ecological relationships, especially pollinators, as nocturnal light can disorient and disrupt their navigation abilities or cause asynchrony between flowering time or nectar production and pollinator activity.

Summary of the chapter:

- Light pollution is artificially created light, especially in cities and their surroundings, disrupting the natural cycle of light and darkness
- In trees, light pollution causes, for example, oxidative stress and lower chlorophyll concentrations

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