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The Interaction of Soil Environments and Woody Plants

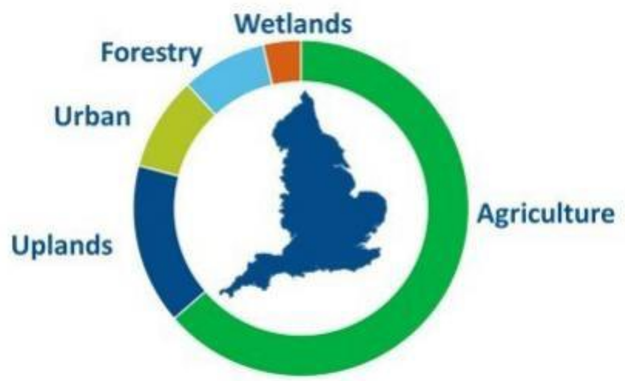
LO 6 Understand optimum soil conditions required for woody plant growth

6.1. Identify signs and symptoms in woody plants of poor soil conditions

A poor-quality soil is one that does not sustain a variety of plants and may have any of the following:
Insufficient drainage (Waterlogging, Puddling) Pans
Prolonged drainage
Nutritional deficiency
pH problems
Depletion of the soil's vegetation and fauna
Poor composition and structure (Compaction)
Saline solution
Contaminated soil

Three major soil issues are erosion, topsoil removal, and soil compaction (dense soil that drains water extremely slowly).

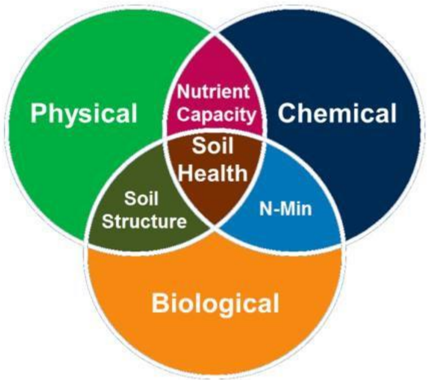
Figure 1 Land use in England



https://www.soilassociation.org/news/2017/october/25/secretary-of-state-commits-to-soil-health/
13,031,001 hectares of land in England are dedicated to farming, with a majority being utilised for improved grassland, horticulture, and arable land. Wooded areas make up 10% of the total land, while 11% is designated for urban development. The type of farming practiced on the land is determined by factors such as climate and soil quality. Regions like Eastern England, known for their fertile soil, primarily engage in agronomic practices like agroforestry. On the other hand, uplands in the north and west of England, characterised by poorer-quality soils, are more suitable for cattle grazing.

Soils in England continue to face three main threats:
Soil erosion by wind and rain. Erosion affects both the productivity of soils but also water quality and aquatic ecosystems.
Compaction of soil reduces agricultural productivity and water infiltration, and increases flood risk through higher levels of run off.
Organic matter decline. The loss of soil organic matter reduces soil quality, affecting the supply of nutrients and making it more difficult for plants to grow, and increases emissions to the atmosphere.

Figure 2 Components of soil health



Soil health is the ongoing capacity of the soil to function as a vital ecosystem that sustains humans, animals, and plants. Various physical, biological, and chemical factors influence soil health (Figure 2). Important factors include acidity and nutrient levels, soil structure and water-holding capacity, biological activity, and chemical contamination. Due to the wide range of soil types, it is crucial to tailor any evaluation of soil health accordingly. For example, healthy upland peat and healthy arable soil exhibit distinct characteristics.

Physical Health of Soil

Soil Compaction

Soil compaction poses a threat to the stability of soils, with agricultural land being more affected than other types of land due to management practices like the use of heavier equipment and longer grazing seasons. Compacted soils are prone to waterlogging and surface ponding, leading to runoff and flooding, which in turn cause pollution and reduce soil nutrient levels. To maintain yields, twice the amount of nitrogen fertiliser is needed. The most severe soil degradation is often observed in areas where winter cereals, maize, or root crops are grown. Potatoes and maize are at a higher risk of having very or severely deteriorated soil compared to land used for winter cereals.

Around 10% to 15% of grassland fields suffer from severe soil compaction and poor soil condition due to overgrazing. The use of heavy machinery at construction sites can also compact the subsurface, and simply replacing the topsoil will not restore the soil's functionality. In England and Wales, approximately 3.9 million hectares of agricultural land are at risk of compaction, especially on clay soils during wet weather. The annual cost of compaction is estimated to be around £472 million, which is three times higher than erosion, highlighting the prevalence of compaction in the landscape.

Soil Erosion

The Soil formation and erosion are natural processes that occur in the environment. It is important to note that future generations will not face a loss of access to soil if erosion does not exceed the rate of soil creation. However, the rate of new soil formation is relatively slow, with just over 1 tonne per hectare being formed annually. In certain areas, erosion occurs more frequently and at a faster rate than soil formation. Reports suggest that around 40% of arable soils in England and Wales are at risk of erosion, but only about 17% of them show evidence of erosion.

The main targets of erosion are peats in highland areas and lighter arable soils on hillslopes. Among the three types of soil erosion found in England and Wales, water erosion is the most severe, followed by wind erosion and removal during harvest. It is worth noting that a bare slope can disintegrate up to 1,000 times faster than a slope covered in vegetation.

Overgrazing by sheep and the use of pathways contribute to soil erosion in upland areas, accounting for approximately 75% of the erosion. Agricultural intensification has also led to an increase in erosion. As fields have become larger, hedgerows have become shorter, leaving the soil more vulnerable to wind and water erosion.

The annual erosion of 2.9 million metric tonnes of topsoil in England and Wales has significant economic consequences, costing approximately £177 million per year. Changes in land use have a significant impact on the risk of soil erosion. For example, replacing winter cereals with permanent grass has significantly reduced the danger of erosion.

Implementing small adjustments to management techniques can have a substantial effect on soil erosion. Studies have shown that incorporating trees into arable crops through shelterbelts and field edges can increase crop yields and potentially reduce soil erosion by almost two-thirds. Additionally, tillage techniques play a major role in the risk of soil erosion, with subpar tractor tramline techniques being responsible for 80% of surface run-off in fields. The wider implications of erosion encompass various aspects. These include the siltation of rivers, which disrupts fish breeding grounds; the occurrence of floods in residential areas and highways; and the negative impact on water quality. Annually, approximately 40 million metric tonnes of dredged material, including eroded soil, are disposed of in the sea. In 2016, urban areas in the UK removed 58.7 million metric tonnes of soil, constituting 26% of the country's total waste production. Although some soil is recycled and used for landscaping purposes, a significant portion, amounting to over 28 million metric tonnes, is sent to landfills. Consequently, soils remain a substantial component, accounting for approximately 55% of the total weight.

Biological Factors

Organic Matter

Soil organic matter plays a crucial role in long-term yields, food quality, and resilience to extreme weather conditions. It also acts as a vital carbon storage facility. Organic material can retain up to 20 times its weight in water, functioning as a sponge and enhancing the soil's resistance to erosion and drought. In England, more than half of the soil's carbon content is found in the top 30 cm of the soil. However, the conversion of permanent pasture to arable crops or temporary grassland leads to a decrease in organic matter in the soil. In most arable soils, 40 to 60 percent of the organic carbon has already been lost.

Peatland covers approximately 11% of England and contains a significant amount of carbon. Unfortunately, less than 1% of England's 1.4 million hectares of peatland remain undisturbed. Peat soils are disappearing rapidly, with peat extraction in the UK happening up to 100 times faster than it can be formed. This alarming rate of extraction could result in the complete disappearance of shallow peat soils within 15 to 40 years. The drying out of peat leads to the decomposition of organic materials and shrinkage, reducing the soil's water absorption capacity. Moreover, it causes a decrease in land elevation and an increase in flood risk.

Soil Biology

There are approximately one billion bacteria per gram of soil, indicating the abundance of life present in it. This translates to the equivalent of 100 sheep's worth of soil organisms per acre, or roughly 5 tonnes. Microorganisms and plant roots work together to release nutrients from bound soils and fix nitrogen in the air. Out of the estimated 11 million species of soil organisms, less than 2% have been identified and categorized. Only two national surveys of the soil invertebrate community have been conducted, one in 1998 and another in 2007. These surveys highlight the fact that arable areas have significantly fewer invertebrates compared to other habitats, although long-term trends cannot be inferred from them.

Intensive agricultural techniques such as monocultures and tilling have a direct impact on the soil's ability to provide ecosystem services. They reduce soil biodiversity, leading to less diverse food webs with fewer functional groups. Earthworms and other soil creatures play a crucial role in maintaining the composition and functionality of soils. Earthworm casts act as pathways for air and water to penetrate the ground. Earthworms also aid in the redistribution of nutrients and the incorporation of organic materials from the soil's surface. According to a recent on-farm earthworm survey, most fields have some earthworms, although 42% of fields may be overworked, as indicated by the scarcity or absence of earthworms. Tillage negatively affects earthworm populations, and managing organic matter does not provide significant help. Furthermore, the use of chemicals and the introduction of invasive species have detrimental effects on earthworms. The mutualistic relationship between plant roots and soil fungi, known as mycorrhiza, is found in 80% of plant species. This partnership forms an extensive network in the soil, enhancing its fertility and water-retention abilities. Soils that have been heavily fertilised and intensely cultivated tend to have reduced diversity and biomass of mycorrhizal fungi. In nutrient-rich forests, mycorrhizal fungi face tough competition from species that are more tolerant to pollution. Consequently, the health of trees may be negatively impacted by these complex ecosystem alterations. The symbiotic association between plant roots and soil fungi, referred to as mycorrhiza, is observed in 80% of plant species. This relationship establishes a vast network in the soil, enhancing its fertility and water circulation. Arable soils that have undergone extensive fertilisation and cultivation typically exhibit lower mycorrhizal fungus diversity and biomass. In forests with high nutrient levels, mycorrhizal fungi are often outcompeted by pollution-tolerant species. As a result, the intricate changes in the ecosystem may lead to adverse effects on tree health.

Chemical Factors

Nutrients

Healthy soil with an adequate amount of nutrients is crucial for the growth of crops. Nutrients need to be replenished in the soil after harvesting to maintain its fertility and productivity. Recycling manures or growing nitrogen-fixing legumes can help replace certain nutrients; otherwise, mineral fertilisers must be used. Regular soil sampling and analysis are necessary for effective soil nutrient management. Planning for nutrient management allows land managers to supply fertilisers according to crop demand, maximising productivity, reducing expenses, and minimising environmental losses. Modern crop varieties have been developed to increase output rather than focusing on nutrient usage efficiency. Atmospheric nitrogen deposition is negatively impacting various vulnerable habitats, reducing species diversity in both calcareous and acidic grasslands, and leading to increased carbon loss from peat bogs. Woody soil in Wales and England has a nitrogen saturation rate of approximately 15%, which may also increase the toxicity of aluminium to plant roots.

Acidification

The pH of the soil greatly affects the availability of nutrients. When the soil becomes more acidic, it can lead to the movement of heavy metals and toxins, which negatively impact both plant and animal communities. Various atmospheric pollutants, such as sulphur dioxide, ammonia, and nitrogen oxides (NOx), contribute to the production of acidic chemicals that are deposited on the soil, thereby lowering its pH. The main sources of these pollutants include power stations, transportation, household heating, agriculture, and industrial processes. In the past, industries released significant amounts of pollutants into the atmosphere, resulting in increased soil acidity. Between 1978 and 1998, the acidity of soils in England decreased. This trend continued for less acidic soils until 2007, but not for more acidic ones. The reduction in industrial emissions and subsequent decrease in sulphur deposition were the primary factors behind this improvement. The variations in soil sensitivity and deposition levels can be observed in the differences between soil types across different geographical areas.

Contamination

Soils have become contaminated due to various factors, including industrial activities that involve the storage and disposal of waste and chemicals. Accidental contamination can also occur through mishaps, spills, and the destruction of buildings containing toxic substances. Before contaminated land can be used for urban development, it must undergo remediation to remove the contaminants.

Contamination of agricultural land is also a concern, with animal manures, waste, and sewage sludge contributing to the deposition of heavy metals and other toxins in the atmosphere. In England alone, it was estimated that around 300,000 hectares of soil were polluted as of 2005. To improve the quality of agricultural soil, over 80% of treated sewage sludge in the UK is applied to it, aiming to increase organic matter and nutrients. However, this sludge may contain substances that contaminate the soil, including metals, microplastics, persistent organic pollutants, and medications.

Studies have shown that medications sprayed on the soil through treated sewage sludge can accumulate in crops and re-enter the food chain. The long-term risks associated with this practice are not well understood, although the amounts consumed are unlikely to pose a health risk. The use of sewage sludge as fertiliser has also been found to be a significant source of microplastics. Household garbage composts often contain plastic, and plastic mulches and fleeces used in horticulture break down into microplastics that accumulate in the soil, absorbing agrochemicals. Chemicals like flame retardants, commonly used in treating plastics, can contaminate the soil. The effects of plastic accumulation in the soil are still unclear, but there is evidence that soil organisms are affected by microplastics, hindering their ability to perform essential ecosystem services. Further research is needed to understand the effects of microplastics entering the food chain and being absorbed by humans.

Climate Change

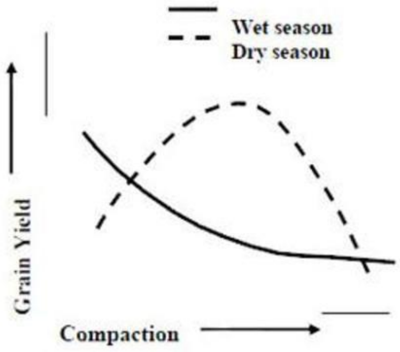
The climate is undergoing a shift. In comparison to the average temperature recorded between 1961 and 1990, the UK has experienced a rise of nearly 1°C. There has been an increase in intense storms leading to heavier rainfall, and the sea level is on the rise. It is projected that summer temperatures could surge by 4°C by the end of the century, with the sea level potentially increasing by at least 1 metre. The consequences of these changes include the loss of valuable agricultural land due to rising sea levels, an elevated risk of soil erosion, and a decrease in soil fertility. The carbon that would typically be released into the atmosphere is being stored in the soil. However, due to alterations in vegetation cover caused by climate change, it is anticipated that the amount of carbon stored in the soil will decrease significantly, necessitating efforts to halt this decline.

Planning for farming will become more complex as soil temperatures and moisture levels fluctuate. Farmers cultivating a variety of crops will face both opportunities and risks. Implementing changes in farming techniques, restoring peatlands, and increasing tree planting can all contribute to improving soil and water quality. By increasing carbon storage, these land-use adjustments can mitigate the impacts of climate change, reduce flood damage, and enhance water quality. Without intervention, soil fertility will diminish, negatively impacting wildlife and the essential ecosystem services provided by soils.

Population Growth
Agricultural and rural land is increasingly being used for construction due to population growth and economic pressures, making it challenging to restore soil functionality once lost. Urbanisation is occurring rapidly, with an average of 200,000 new homes built each year, yet demand remains unmet, and only half are constructed on brownfield sites. The remaining homes must focus on preserving soils, preventing organic matter accumulation, and maintaining essential ecosystem functions. Expanding populations may require more intensively managed agricultural land, historically achieved by converting grasslands. As waste production rises with population growth, there will be a greater need for soil to handle, retain, and potentially recycle waste. To achieve this, it is crucial to minimise any adverse impacts, as more waste is being spread on land. While this may benefit soil health, it is essential to ensure contamination risks are minimised.

Emerging pollutants
In 2016, approximately 16,600 metric tonnes of pesticides and herbicides were used on British farms. Recent studies have shown that glyphosate, a weed killer previously thought to break down in the soil, can actually persist for longer periods. Moreover, glyphosate has been found to negatively affect soil organisms responsible for maintaining soil nutrients and structure. This chemical has been detected in human food and is suspected to be carcinogenic. To reduce pesticide usage, new insecticides have been developed, some of which may harm soil organisms. For example, clothianidin, a neonicotinoid currently banned for outdoor use in the UK and other European countries, is highly toxic to earthworms and remains in the soil for extended periods.
The misuse of antibiotics has led to an increase in antibiotic resistance genes, which are accumulating in soils due to the application of manures and processed sewage sludge. These genes have the potential to permanently alter the composition of the soil's microbial community, spreading outward and posing challenges for healthcare by making it harder to treat diseases.
The application of sewage sludge on land and the use of pesticides have resulted in soil contamination by nanoparticles. Silver nanoparticles, introduced to soils through sewage sludge, have been shown to be harmful to plants and can affect root development. Nanomaterials present in biosolids can change the types of soil microbes and disrupt the uptake of nitrogen by plants, negatively impacting plant growth rates. Furthermore, these nanoparticles have been found to harm bacterial populations. Given the relatively recent nature of this hazard, further research is necessary to determine the extent of the problem.

Soil problem 1
Soil Compaction
Soil compaction is a prevalent issue in various locations, including heavily used recreation areas, construction sites, urban areas, timber harvesting sites, fruit orchards, agroforestry systems, and tree nurseries. It can occur naturally through soil settling or slumping, or it can be caused by tillage tools, heavy machinery, pedestrian traffic, animal trampling, and fire. Compaction has significant impacts on soil structure and hydrology, leading to increased soil bulk density, breakdown of soil aggregates, decreased soil porosity, aeration, and infiltration capacity, as well as increased soil strength, water runoff, and soil erosion. This compaction can result in physiological dysfunction in plants, often leading to reduced water absorption and leaf water deficits. Moreover, compaction induces changes in the levels and balances of growth hormones in plants, particularly increases in abscisic acid and ethylene. The absorption of major mineral nutrients is also hindered by compaction in both surface soils and subsoils. Plants growing in highly compacted soil experience a decreased rate of photosynthesis, primarily due to smaller leaf areas. As soil compaction worsens, root respiration shifts towards an anaerobic state. Severe soil compaction has detrimental effects on the regeneration of forest stands by inhibiting seed germination and seedling growth and by causing seedling mortality. Furthermore, the growth of woody plants beyond the seedling stage and the yields of harvestable plant products are significantly reduced by soil compaction due to the combined effects of high soil strength, decreased water infiltration, and poor soil aeration, all of which result in a decreased supply of physiological growth requirements at meristematic sites.



In a year with low rainfall, crop yields gradually increase alongside a slight rise in soil compaction at very low bulk densities. Slightly compacted soil can promote faster seed germination due to improved seed-to-soil contact. To facilitate this process, packer wheels on corn planters are designed to provide gentle compaction while ensuring proper seed placement. As soil compaction levels surpass the ideal threshold, yields begin to decline. In dry years, restricted root growth caused by soil compaction can lead to stunted, drought-affected plants. Without timely rainfall and strategically applied fertilizers, yields will inevitably decrease. Increased compaction results in lower yields during wet conditions. In years with high precipitation, soil compaction hampers soil aeration and boosts denitrification rates. Moreover, root infections may become more widespread. These factors collectively add stress to the crop, ultimately diminishing overall output.

<u>Soil problem 2</u>

Soil Sealing

Soil sealing refers to the process of covering or destroying soil with impermeable materials like asphalt or concrete during construction or development projects. This hinders the soil's natural functions and can lead to irreversible damage. In the UK, over 22,000 hectares of land were converted to urban areas between 2008 and 2012, excluding spaces like parking lots, which are not accounted for in official reports. The amount of undeveloped land used for construction in England more than tripled from 2013 to 2017, with an average of 15,800 hectares annually. This rapid pace of development is resulting in the loss of agricultural land and green spaces, with urban front gardens increasingly being covered by pavement. Block paving has been a common method used to seal off soil, further contributing to the issue of soil sealing.

Examples of sealed soils. Partially sealed soils: A—profile no. 41; B—profile no. 6; C—profile no. 28; completely sealed soils: D—profile no. 19; E—profile no. 5

To flourish, trees require an ample quantity of loose, well-ventilated, and damp soil. These specific soil attributes enable tree roots to acquire the essential nutrients, oxygen, and water necessary for robust development. Interestingly, these are the very components that constitute the soil in natural forests. Unfortunately, densely populated urban areas often lack these favourable soil conditions.

Nutrients
Seventeen essential soil nutrients have been identified. The tree's roots absorb other nutrients, such as water, from the soil, while carbon and oxygen are directly obtained from the air. Along with various trace elements, the key nutrients consist of calcium, sulphur, and magnesium. However, the primary nutrients are as follows:
1. Nitrogen is necessary for the healthy growth of leaves and stems.
2. Phosphorous: crucial for promoting root development.
3. Potassium is vital for supporting the overall health of a plant, especially its immune system.
Even with appropriate soil preparation, watering, and mulching, plants may fail to thrive, indicating a possible deficiency in nutrients. Fruits and vegetables, container plants, and those growing in highly acidic or alkaline soils are particularly susceptible. Insufficient nitrogen, magnesium, or potassium can result in yellow or reddish leaves, stunted growth, and inadequate flowering.

Few examples of nutrient deficiencies and their remedy:
Symptoms include thin, pale yellow plants or leaves that may occasionally display pink hues. The cause of this issue is a lack of nitrogen, which hinders proper growth and encourages the development of green, leafy plants. Nitrogen is easily washed away from the soil during winter rains, resulting in a nitrogen deficiency during the spring when plants are actively growing. The most common reason for yellow leaves in the spring is a nitrogen deficit. To address this problem in the long term, it is recommended to mulch with organic materials like well-rotted garden compost or manure to stabilise nitrogen levels. In the short term, applying high-nitrogen fertilisers such as sulphate of ammonia or pellets of poultry manure will effectively resolve the issue.

Symptoms of potassium deficiency may manifest as yellow or purple leaf discoloration, browning along the leaf margins, and stunted fruit or flower growth. The lack of potassium affects crucial processes such as photosynthesis and water absorption in plants. Potassium plays a vital role in promoting fruit development, flowering, and overall plant resilience. In areas with light, sandy, or chalky soils that easily lose potassium, deficiencies are more common. Conversely, clay soils can retain potassium. To address potassium deficiency, it is recommended to use potassium-rich fertilisers such as sulphate of potash, tomato feed, or organic sources derived from sugar beetroot processing.

Phosphorus deficiency results in stunted growth, and the appearance of pale, yellow leaves is indicative of this condition. The development of robust roots and shoots relies on an adequate supply of phosphorus. While phosphorus deficiencies in the soil are rare, they may occur in regions with dense clay soil and abundant rainfall. To address this issue, it is recommended to utilise fertilisers such as superphosphate or bone meal as a remedy.

Drought or waterlogged soil can lead to wilting in plants. When the roots are unable to provide enough moisture to the stems and leaves, the plants start to wilt. It is important to note that short periods of wilting do not harm the plants. However, on hot days, plants may wilt due to excessive evaporation from the leaves, which the roots cannot replenish quickly enough. If there is enough moisture in the soil, the plants will absorb water in the evening to regain their turgor. Nevertheless, prolonged drought can cause severe damage to plants, including yellowing, leaf scorch, browning, leaf drop, or stunted growth. Additionally, extended periods of drought can hinder the formation of flowers and fruits. When a plant is in bloom, severe heat and water stress may result in scorching or browning of flower buds and blossoms. It is important to remember that different plants have varying levels of tolerance to drought, and some may even die suddenly after prolonged periods without water.

Chlorosis, a condition where typically green leaves turn yellow, is a result of a deficiency in chlorophyll. This deficiency can be caused by various factors, either individually or in combination. Some of the most common causes of chlorosis in trees and plants include nutrient shortages due to excessive pH and soil alkalinity, dryness, inadequate drainage, and soil compaction. Tree species such as pin oak, red maple, white oak, river birch, tulip tree, sweet gum, bald cypress, magnolia, and white pine are often prone to displaying chlorosis.

Essentially, necrosis is the scientific term for the death of plant tissue. Necrosis usually occurs in a specific area, like leaves, roots, or stems. Often associated with bacteria, viruses, fungi, or parasitic insects, necrosis can also be caused by watering plants too much or too little, a lack of nutrients, or improper amounts of sunlight. Conditions leading to necrosis depend on the plant species, as tolerances to diseases and requirements for sunlight, water, and nutrients vary widely across the plant kingdom.

Die-back or canopy decline can occur rapidly or gradually over a period of ten years or more. The upper part of the canopy may be experiencing die-back or deterioration due to various reasons, including the following:
1. Soil was added on top of the root system. If this occurred a long time ago and the tree has grown significantly, there may be limited solutions. However, if the soil was recently added (within the past year), carefully removing it without causing harm to the roots could be beneficial.
2. Soil compaction caused by vehicle or pedestrian traffic.
3. Drought conditions may be causing the tree to die. Consider irrigating the soil beneath the canopy, similar to how a lawn is irrigated.
4. The neighbourhood may have experienced flooding a few years ago.
5. High winds, potentially from a hurricane, may have occurred in the area within the past year or two. The salty air blowing against the canopy could have caused twig die-back.
6. The tree may have a vascular condition that is hindering water flow to its upper part.
7. The available soil area for the trees may have been depleted. Acting in such cases is challenging.
8. The tree may be exposed to persistent wind or salt spray.
9. A newly planted tree may have a weak root system or insufficient watering.
10. The trunk may be constricted by a root, leading to decline.
11. The roots may be infected by Armillaria or another type of root-attacking fungus. Addressing this issue is difficult.
12. Ganoderma infection may be present in the lower stem and roots.
13. The highest central section of the canopy may be restricted by lower branches. This is more common in trees with opposite branching patterns. Once die-back has begun, it is challenging to halt it. The best approach is to perform preventive pruning when the tree is young to establish a strong structure.

https://soil.copernicus.org/articles/7/661/2021/
https://www.forestresearch.gov.uk/tools-and-resources/fthr/urban-regeneration-and-greenspace-partnership/greenspace-in-practice/practical-considerations-and-challenges-to-greenspace/soil-compaction-practical-considerations/
https://extension.umd.edu/resource/common-soil-problems https://hort.ifas.ufl.edu/woody/dead-branche-stop.shtml
https://www.intechopen.com/chapters/38612

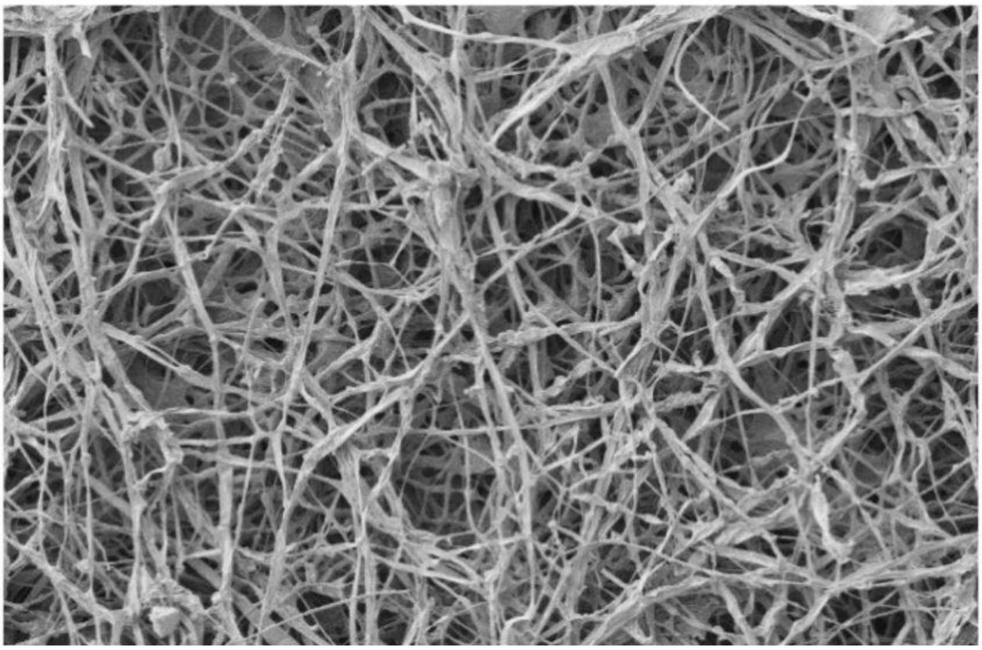
6.2. Identify a minimum of two methods of improving soil conditions for woody plant growth

Method 1
Mycorrhizae
Urban horticulturists utilise mycorrhizal inoculants to help plants withstand harsh environmental conditions in urban areas. These inoculants are particularly effective in aiding plants to thrive despite the intense heat and water scarcity they may face more frequently due to climate change, especially in urban settings. The key advantages of mycorrhizae include enhanced nutrient absorption (such as phosphorus, copper, zinc, and manganese), improved resilience against stresses associated with transplanting, nutrient deficiencies, root rot, and drought, as well as optimal recovery and growth post-transplanting, leading to increased plant vigour, flowering, and fruit and vegetable yield.

Fungi

Image by Ellen Larson/**wiki** (**CC BY 2.5**).
A specific kind of mycorrhizal fungus that coexists symbiotically with plant roots. In exchange for sugar, these fungi assist plants in absorbing scarce soil nutrients like phosphate.
https://www.nhm.ac.uk/discover/soil-degradation.html

It has come to light that enzymes produced by fungi have the capability to break down wood, DDT, and cigarette butts. By converting polycyclic aromatic hydrocarbons (PAHs) into soil and wood into less harmful chemicals, fungi offer potential solutions to enhance plant health, eliminate toxic substances from the environment, and even transform waste into food and medicine. Mycorrhizal fungi, which form symbiotic relationships with tree roots, play a crucial role in maintaining the well-being of plants and ecosystems. Through the interconnectedness of their hyphae, fungi can efficiently transport nutrients in various directions, resembling the spreading roots of plants. They serve as a remarkable example of adaptive forms and networks within a biophilic metropolis. Mycelium, a network of interwoven hyphae, can create vast networks, demonstrating the potential for collaboration and cooperation. By embracing the mycelium as a model for relationships, we can learn from the mycorrhizal connections and witness the benefits of increased connectivity and cooperation among different species.



Microscope photo of intertwining mycelium: Citation: Cartabia, M.; Girometta,C.E.; Milanese, C.; Baiguera, R.M.; Buratti, S.; Branciforti, D.S.; Vadivel, D.; Girella, A.; Babbini, S.; Savino, E.; et al. Collection and Characterization of Wood Decay Fungal Strains for Developing Pure Mycelium Mats. J. Fungi 2021, 7, 1008.
https://doi.org/10.3390/jof7121008 Creative Commons

Mycorrhizal fungi intertwine with the roots of trees, significantly increasing their ability to capture nutrients by ten to a thousand times. These fungi also establish connections with other plants, forming a vast and adaptable network in the soil. This network enables the transfer of nutrients from one plant to another, creating a resilient web. Moreover, mycorrhizal fungi produce a sticky protein called glomulin, which aids in binding soil particles together and improving soil stability and health. This interconnected network serves as the basis for ecosystem resilience. It is worth noting that approximately 95% of vascular plant species form mycorrhizal connections. Evidence of this symbiotic relationship can be traced back to the fossils of the earliest land plants, dating back around 460 million years. As fungi possess the ability to break down rocks and other materials into usable nutrients for both plants and themselves, they play a crucial role in the initial survival of plants on land.

Research conducted by Dr Suzanne Simard and numerous other researchers has unveiled the intricate connections formed by fungi that encompass and support the entire ecosystem. Referred to as "mother trees" by Dr Simard, these trees serve as the foundation of the forested ecosystem. The mycorrhizal network serves as a conduit through which the ancient wisdom of these trees can convey vital information regarding pests, water, and nutrients. Mother trees can transfer nutrients to their offspring through the fungal network, while fungi can promote the growth of other microorganisms to safeguard the plants. If trees linked to these networks perish, they will transfer carbon and essential nutrients to neighbouring trees via the fungal hyphae. Remarkably, this nutrient exchange can occur between different tree species, such as the transfer of nutrients from a birch tree basking in the sunlight to a Douglas fir in the shade during the summer, followed by the Douglas fir reciprocating the nutrient transfer to the birch during the winter.

The mycorrhizal network relies on the presence of living plants and organic matter in the soil. Disruption of either component can have detrimental effects on the mycorrhizae. Furthermore, compacted soils resulting from vehicle and equipment use can also compromise soil health. The reduction in space between soil particles limits the ability of roots and mycelium to breathe and grow, as well as restricts the ability of mammals to burrow and dig. Additionally, herbicides like glyphosate can act as fungicides, disrupting soil fungi.

https://www.ted.com/talks/suzanne_simard_how_trees_talk_to_each_other/transcript
https://pubmed.ncbi.nlm.nih.gov/33551324/ https://arboriculture.wordpress.com/2016/03/19/
https://efuf2016.wordpress.com/2016/03/17/resilience/

Method 2

Add organic matter

The term "soil quality," which is synonymous with "soil health," is widely debated when discussing present and future land use. Numerous definitions of soil quality exist (e.g., Bastida et al., 2008; De La Rosa, 2005; Pankhurst et al., 1997; Doran, 2002; Kibblewhite et al., 2008), but they all revolve around the notion that soils are acceptable for contemporary applications and will probably remain so in the future.

Over the last two centuries, the combination of increased agricultural production and industrial pollution has led to soil degradation. In England, three main factors continue to threaten the soils: erosion by wind and rain, compaction, and a decline in organic matter.

Soil degradation in England has been exacerbated by increased agricultural production and industrial pollution over the past 200 years. Three key factors continue to pose a threat to the soils: erosion by wind and rain, compaction, and a decline in organic matter.

https://www.theukrules.co.uk/rules/business/farming/soil-protection-review.html

Adding organic matter to soil has numerous benefits, serving as a key element in addressing various soil problems. Organic materials enhance soil quality by providing structure, micronutrients, supporting microbial life, and preventing erosion due to compaction. Healthy soil is typically characterised by a high organic matter content (typically 3-4% or more), proper aeration, a balanced nutrient profile, and the right combination of sand, silt, and clay, along with a thriving population of beneficial microorganisms.

The UK Government recommends following steps to increase organic matter:

The best results from organic matter inputs will be seen when they are added to underperforming soils. This may apply to soils that have

inadequate, erratic, or uneven grass growth

crop diseases or unwelcome weeds

Winter surface waterlogging occurs quickly
drought issues during the summer

The likelihood of unhealthy soils is highest in areas with historically low organic matter inputs. Organic matter inputs should be prioritized on land were
You consistently cultivate
root crops are part of the rotation
crop residues are not returned to the soil
Grass and cover crops are not included in the rotation.

The UK government provides recommendations for adding organic matter to the soil. Instead of solely using crop roots or stubbles, it is advised to utilise crop residues and discard straw. For fields with limited organic matter, cultivating a cover crop or incorporating green manures can help enrich the soil. Another effective method is sowing a mixture of deep-rooting grasses and herbs as a cover, which is particularly beneficial for compacted soil. Organic matter can also be added to the soil through various sources, such as animal slurries and manures, whether from your own farm or imported. Digestates, which are the residues produced from the anaerobic digestion of biodegradable substances like domestic food waste, can also be utilized. Additionally, manures, specially bred plants, biosolids, compost, wood, crumbling paper, and by-products of food processing and abattoir can contribute to the organic matter content in the soil.

To prevent the loss of soil organic matter, consider adding more long-lasting organic materials with a high carbon-to-nitrogen ratio, like wood chips, sawdust, straw, or paper crumble. Transitioning to no-till or minimum-till farming methods can also reduce soil disturbance. Additionally, minimising the impact of livestock and machinery on soil compaction, manually breaking up tramlines to prevent runoff and erosion, and maintaining vegetation growth to shield the soil from temperature fluctuations are all effective strategies. In the case of naturally wet arable land, converting it into continuous grassland, rush fen, or pasture can help preserve soil health.

https://defrafarming.blog.gov.uk/increase-soil-organic-matter/
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<u>6.3. Identify a minimum of two fertilizers for use with woody plants</u>

There are several primary reasons to consider fertilisation in an urban setting. Firstly, it is a cost-effective method to replenish the nutrients that urban trees are deficient in due to factors such as living in less densely forested areas and the need for leaf cleanup. Additionally, healthy urban trees that are fertilised are less susceptible to drought and insect infestations. Fertilising urban trees also helps them reach their full potential by restoring lost nutrients and promoting root growth during the dormant winter months, ultimately preparing them for optimal health in the spring.
Tree avenues have been a significant feature in both rural and urban landscapes in Britain for centuries. Originating in Europe and gaining popularity in the UK in the 17th century, these avenues are not always managed with the necessary care today. Failure to implement proper management practices can result in the decline of existing avenues or the inability to regenerate them.
Changes in land use, soil compaction, and alterations in drainage patterns over time may have impacted the ground conditions around the trees in the avenue. Improving these conditions can be achieved through soil aeration, addressing drainage issues, and controlling grazing animals in the vicinity. However, it is crucial to only apply fertilisers after conducting a foliar analysis to determine if there is a nutritional deficiency.
Enhancing the physical conditions of the soil post-tree planting can be quite challenging, if not nearly impossible, and is therefore seldom carried out. Prior to planting, whether it be a single tree or a whole row, it is advisable to improve drainage and reduce compaction across a large area by breaking up the soil to a depth of at least 0.5 m (e.g., through ripping). Before commencing this process, it is essential to survey for any existing services and drains. Additionally, the soil within the planting pit should be adjusted, if needed, before the actual planting takes place. Utilising organic manure, such as well-rotted farmyard manure, spent mushroom compost, and digested sewage sludge, can provide both organic material and a gradual release of nutrients, aiding in the initial survival and early development of the tree. However, caution should be exercised when using such additives, as they may increase soil moisture levels and make the soil more susceptible to soil-borne diseases like Phytophthora, especially in soils that retain moisture (refer to Strouts, 1981).

Highway Trees specification in England

Imported topsoil must be of good quality, have a light texture, and meet the requirements of the BS 3882 General Purpose Category. If a non-BS 3882-compliant topsoil is proposed for use on site, it is necessary to conduct the following tests:

1. The pH level of the soil should fall within the range of 5.5 to 7.8.
2. The organic matter content should exceed 5%.
3. The nitrogen (N) content should be higher than 0.2%.
4. The phosphorus content should be above 45 mg/kg.
5. The potassium content should be greater than 240 mg/kg.
6. The magnesium content should be higher than 80 mg/kg.

Additionally, more comprehensive testing should be carried out to determine the presence of phytotoxic elements such as copper, nickel, zinc, and zoot.

With the growing demand to convert brownfield lands into residential and commercial areas, there is a greater focus on incorporating greenspaces to enhance the overall environment for residents and workers. However, this task often involves cultivating vegetation in less-than-ideal conditions. To ensure successful restoration, it is crucial to prioritise the foundational aspects of plant cultivation for long-term sustainability.

Brownfield sites often present soil-related challenges. These areas frequently have infertile soils, lacking essential nutrients such as nitrogen, potassium, and phosphorus. As a result, it becomes necessary to regularly supply these nutrients during the initial establishment phase to prevent trees from experiencing nutrient deficiencies (refer to Figure 1).

Figure 1 Mineral nutrient deficiency in conifer branches.

There is often a lack of organic matter necessary to retain any nutrients provided as fertiliser. Additionally, contaminants may be present, which can either compete with mineral nutrients for binding sites on the soil matrix or hinder the absorption of plant nutrients. Fertilisers are divided into two categories: mineral fertilisers and organic fertilisers. Mineral fertilisers are synthetic and are quickly released into the soil, especially nitrogen (N), although the release of potassium (K) and phosphorus (P) can be delayed. They have the advantage of producing rapid growth responses, making them useful for addressing immediate fertiliser deficiencies. Fertilisers can also be applied during specific plant growth stages or seasons when additional nutrients may be beneficial. However, if there is insufficient organic matter (common in brownfield soils), the fertiliser will not be retained in the soil and may leach out before benefiting the plants. This leaching can occur after heavy rainfall or water movement on the site, or if the plant roots are too immature to utilise the fertiliser. It is important to prevent mineral fertilisers from leaching, as they can contaminate water sources downstream. Therefore, it is crucial to avoid exceeding water quality standards by overapplying mineral fertilisers.

Table 1 shows the different formulations available for N, P and K.

Table 1 Range of formulations for N, P and K mineral fertilizers.

Mineral fertilizer	Formulation	Typical % composition
Nitrogen (N)	Ammonium nitrate	34
Ammonium sulphate		21

Urea		46
Phosphorus (P)	Superphosphate	19
Triple superphosphate		47
Ground mineral phosphate		30
Potassium (K)	Muriate of potash	60

Mineral fertilisers are commonly applied during or after planting, but they can also serve as a top dressing to address any mineral deficiencies that may arise later on. The most effective method to determine the need for additional sprays is by sending foliar samples for analysis. It is recommended to use organic fertilisers shortly before or at the time of planting or sowing for most plants and trees, as they are challenging to apply at a later stage.
Organic fertilisers are typically derived from waste byproducts like animal, green, and human waste, and they generally have a slower release compared to mineral fertilizers. They can supply essential plant nutrients and organic matter.

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6.4. Describe a minimum of two methods of application of fertilizer to mature trees

There are various methods available for applying fertiliser to trees and shrubs. The choice of method depends on factors such as soil characteristics, location conditions, cost, and the type of fertiliser being used.
One common approach used by professional arborists is liquid soil injection. This method is preferred because it is quick, easy, and allows for rapid uptake of fertiliser. Liquid fertiliser is injected into the soil under high pressure, with injection locations spaced 2-3 feet apart and 8–12 inches deep. This method also offers slow-release liquid injectable fertilisers as an alternative.
Another method involves drilling holes into the soil and evenly dispersing granular fertiliser among the holes. This procedure is effective in breaking up compacted soils and allowing fertiliser, water, and air to reach the root zone. The holes are drilled to a depth of 8–12 inches and spaced 2-3 feet apart in concentric circles around the tree. It is recommended to start about 1/3 of the way from the trunk to the drip line and extend 1-3 feet beyond the drip line. The holes can be left open or filled with compost, peat, or other organic material. This method is particularly useful when there is a risk of harm to fine turf due to high fertiliser rates or fertilisers with a high salt index.
Surface application is another option, where granular fertiliser is applied to the soil surface around trees and shrubs. This can be done by hand or with a machine spreader. This method is quick, simple, and cost-effective. Recent tests have shown that it is just as effective as other techniques in supplying nutrients to plant roots. It is especially beneficial for mulched areas and shrub borders. In some cases, if a tree is growing in a lawn area, it may absorb nutrients from surface fertiliser treatments to the lawn and may not require additional fertiliser.
Overall, the choice of fertiliser application method depends on the specific needs and conditions of the trees and shrubs being treated.
Fertiliser spikes and stakes: This method entails inserting solid rods containing a predetermined amount of fertiliser into holes in the soil surrounding woody plants. However, the wide spacing of the holes and the delayed release of nutrients limit the effectiveness of this approach. Therefore, it is not recommended.
Foliar fertilisation, on the other hand, involves spraying liquid fertilisers onto the leaves of plants. This technique is primarily used as a temporary solution for mild nutrient deficiencies. However, it is not efficient in providing enough essential nutrients for optimal growth. The most effective time for foliar feeding is when micronutrient solutions are sprayed onto the foliage shortly before or during the growth period.
Tree trunk injections, on the other hand, are mainly used to address minor deficiencies of specific elements like iron, manganese, and zinc. This method can be particularly useful in urban areas where applying fertilisers to the roots or surface of the soil is impractical.

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