Tree Allelochemicals: Ways and Means

by Dr. Kim D Coder, Daniel B. Warnell School of Forest Resources,
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Allelopathy and competition between individuals on a site are collectively called interference. The allelopathic component of interference is a significant tree health care issue usually overlooked. Allelopathic chemicals (allelochemicals) are conveyed into the environment by trees and ecologically modify growing sites. The way these allelochemicals escape the tree and their general chemical form are reviewed below.

The main pathways of allelopathic effects in trees are through leaves, roots, stems, microorganisms, and some miscellaneous means, all of which will be individually covered below..

Leaves – Leaching and surface erosion are widespread natural processes in which materials are lost to water. Any moisture that wets the leaf surfaces can cause leaching. Rain washes materials out of trichomes (plant hairs), cracks, and oil glands on living leaves. All materials inside the tree can be leached out of the tree -- some of which have an allelopathic effect on the site. A number of the oil-soluble chemicals are minutely soluble in water and ecologically active. Oil-soluble materials are also eroded attached to other materials and swept along in dust and shed plant cells.

Younger leaves are less susceptible than older ones to leaching. Leaves that have smooth, waxy surfaces are not wetted easily and are less likely to be leached. Leaves that are relatively large, flat, and pubescent (covered with trichomes) are easily wetted and leached. Acidic precipitation can significantly increase leaching through its damage to leaf surfaces. The leaf cuticle is not a solid coating, but is made of many individual layers with cracks, openings, gaps and trichomes, all of which make the cuticle more permeable to water and leachable. Stomates are not a primary pathway of substance loss by leaching. Additionally, materials may be actively deposited on the leaf surface and washed away.

Materials, including allelochemicals, leached from the leaves can be reabsorbed by roots, stems, and foliage of the same tree or any other organism in the area. Water leaches or erodes a number of allelochemicals from leaves and buds which act as either a growth simulator or as a growth inhibitor, depending upon dose and organism involved. Specific associations of different organisms are the natural result of rain-wash chemical impacts. The edge of the tree crown can be a clear line between high and low allelopathy effects.

Another process of allelochemical loss from leaves is by volatilization (for example – terpene evaporation). These volatile compounds combine with leaf wax and bark surfaces of the same tree or other living things. More importantly, the volatile materials may combine with soil particles and act to form a crust or change soil properties inhibiting growth and seed germination. Dry soil particles in particular, absorb the volatile substances from the atmosphere and change ecological functions.

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Another means of allelochemical loss from the leaves is through decomposition of dead material. Leaching losses are greatly accelerated when tissue dies or is damaged. Dead organic matter is easily leached of allelochemicals. Microorganisms can convert immobilized allelochemicals into active forms, especially allelopathic chemicals tied-up with sugar. Leaf and fruit litter can contain a large amount of allelopathic chemicals which are slowly released over several seasons. This slow release of allelochemicals can modify species composition on a site for years after the originating tree (allelopathic conveyor) is dead. Some leaf-based mulches would be suspects of conveying allelopathic effects.

Roots – Another avenue of allelopathic effect is through tree roots. Root exudates are substances released into the soil by healthy, intact roots. The major area of exudation is in the young, non-woody roots, which can have high concentrations of allelopathic chemicals present and are also thinly protected from the environment. The various types and portions of the roots exude different materials and in greatly differing concentrations.

The root development zone immediately behind the primary root tip in absorbing root fans are a primary site of exudation. Exudates are also concentrated in the root hair zone (a mycorrhizal and pathogenic fungi infection zone) and the area where new lateral root are generated. It remains unclear whether allelochemicals exuding from roots is a active, selective process or an accidental leakage of materials before secondary growth and bark development occur.

Decomposition of roots yield another source of allelopathic chemicals. Death and physical damage to parts of the root system, allow leakage of cell materials into the environment. The turn-over (growth, decline and death) of absorbing root systems many times during the same growing season, allows significant concentrations of allelochemicals to be shed into the soil. Damage to roots and the ensuing compartmentalization process can leave many types of tissues open to soil organisms and open to release of allelochemicals.

Some allelopathic chemicals are released upon cell death, while other materials are released by soil organisms. Microorganisms can facilitate allelochemical release by degradation of cell walls and by stripping allelochemicals from chemical bonds. Soil weathering of old bark can liberate a slow trickle of allelochemicals. Because absorbing root fans are stimulated to grow in and below rich organic matter decay pockets, the allelochemicals from living roots, absorbing root turn-over, and decaying organic matter develop localized areas of high allelopathic chemical concentrations.

Stem – A third pathway for allelopathic chemical release in trees is through stem-flow — water flowing over the twigs, branches, and stems – leaching materials as it flows. Stems and branches of deciduous trees, and foliage in evergreen trees, are also weathered and leached during the dormant season, producing year-round chemical inputs. The amount of stem-flow ranges from 1 and 16 percent of the total rainfall on a given site and species. The stem-flow water is deposited on the soil in a small circular band around the stem base. There are also a number of bark surface organisms that add their own allelopathic agents to the stem-flow, especially lichens.

Microorganisms — Microorganisms have a large impact on the total allelochemical load on a site. Each individual can generate their own allelopathic chemicals which affect other organisms, including tree roots. Fungi and bacteria can transform exudates into inactive materials, break them apart, or process them into allelopathic agents. Microorganisms can influence and interfere with the elaborate growth regulation signals surrounding fungal growth and infection in mycorrhizal associations. Mycorrhizal fungi and mycorrhizae can produce allelochemicals affecting other living things. Trees and selected associates ecologically modify their environment for more effective and efficient interference.

Microorganisms also affect the release of allelopathic agents from inert materials by decay and respiration. Glycosides (glucose bonded compounds) are one important class of compounds because microorganisms break-apart these materials to use the glucose, leaving the active allelochemical behind. As decay continues, many break-down products are released, some from the organic material source and some from the decay organism. Eventually everything inside a tree is consumed, released, or transformed. Years after tree death, the allelopathic and decay signature of the tree can still be chemically extracted from the soil. Some of the lignin-based products and humic acid residuals can be recovered after decades. All sites have some type of allelochemic heritage and history present.

Other Paths – Other pathways of allelopathic effects are seeds, fruits, and pollen. On a small scale, seeds and fruits chemically affect the microflora of a site as the seed surface covering breaks-down. Because of the relative large concentrations of allelopathic chemicals in the reproductive materials, they can modify their own micro-sites where they fall. Concentrated together, they can produce significant allelopathic effects. Pollen allelopathy is an interesting study area which might determine fertility problems in trees and allergy problems in humans.

Types of Chemicals

The allelopathic chemicals are diverse and large in number. The chemistry and catalog of these materials are too complex to be discussed here. Generally, the chemicals responsible for allelopathy are listed among the secondary pathway substances. These substances are not considered essential to the main-line growth and development processes in a tree. One means of dividing allelochemicals produced by trees is: terpenes, phenolics, alkaloids, nitriles, and other substances.

Terpenes — Terpenes play a defensive role in trees. Terpenes are the major component of essential oils in many trees, act as tree scents, and are a component of resins. Terpenes are released by vaporization into the air or leached in small amounts by water. These compounds cause poor growth and aggravate other site problems when released.

Phenolics — Phenolics are a large group of aromatic compounds. Most smaller phenolics in trees have been implicated in allelopathy. Phenolics occur in the essential oils of trees and are responsible for some tree scents. Phenolic compounds protect trees against infections from microorganisms and injury from higher animals. Tannins are phenolic polymers and water soluble. The tannins protect trees from animal grazing and injury, and act as allelochemics. Many phenolics occur combined with sugars.

Alkaloids – The alkaloids comprise a large mixture of nitrogen containing materials commonly found in many toxins. Trees developed these compounds as repellents and poisons. Many of these compounds are attached to sugars for storage. An associated group is the nitriles or organic cyanides. The compounds have a great ecological importance because prolonged leaks of small amounts can greatly change plant, animal, and microbe distribution on a site. Because of their nitrogen contents, alkaloids and nitrile do not last long in the environment.

Other Chemical Types – The final groups of chemicals involved in allelopathy is not a related set of compounds, but a number of miscellaneous materials from many different sources. For example, mustard oils are nitrogen- and sulfur-containing compounds that can volatilize and leach, causing major ecological changes. A number of fatty acids have been shown to lead to a loss of soil fertility. Alcohols and ketones formation accelerate in tree roots during periods of poor aeration and have been shown to have allelopathic impacts.

There are a host of different organic acids which influence almost every aspect of growth and development in living things. Some allelochemicals are analogs of normal amino acids and can disrupt protein synthesis. One common allelopathic chemical is oxalic acid, visible as crystals inside cells, which is released upon cell death. Chemicals similar to natural growth regulators can be released into the environment, mimicking herbicide effects.

Toward Natural Pesticides

One of the great potentials for some allelopathic chemicals, or genetically modified allelochemicals, is for use as pesticides and growth regulators. Allelopathic materials have been proven to be effective, targeted, and rapidly dissipated or destroyed in the environment. They influence nematodes, fungi, bacteria, insects, and mites, as well as weeds. Careful selection of allelochemical materials could produce a series of specific pesticides for landscape use around trees. Use of these pesticides could influence pest populations, improve symbiotic organism infection and growth, and accelerate site changes favorable to new trees. Allelochemicals might be used to induce ecological changes that would positively influence beneficial organisms and interfere with pests.

Implications for Tree Management

Allelopathy influences the ecology of the tree-soil interface and modifies relationships between organisms. Allelopathic effects are subtle and additive in generating ecological changes. As with any process, material, or tool, allelopathy can be used, abused, or neglected. Proper tree management demands a clearer understanding and formulation of tree-literate management regimes incorporating allelopathic concepts. Below are listed general review articles which summarize allelopathic concepts and models.

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