Soils, Fungi and Plant Partnerships

by Marcel Beauchamp

As gardeners, we have a vested interest in healthy soils. And as we all know, a healthy soil leads to healthy plants. How many times have you heard master gardeners say "*Feed your soil and you feed your plants*!"? Of course, we know that adding organic matter to soils not only feeds plants, but also improves the quality of soils and encourages a healthy balance of bio-organisms which keeps soils alive and plants thriving. In tandem with that, people are more aware of the dangers to the environment and ecosystems that comes with overuse of traditional toxic pesticides and chemical fertilizers. There is a move towards using less toxic and more natural products which are less disruptive to ecosystems and respect the integrity of the environment.

This isn't just part of an organic gardening "trend". Individuals realize that if we don't do something to protect ourselves and the environment from the harmful effects of many of these products, then we will continue to be part of the problem, instead of part of the solution to what ails the earth. As such, public demands for safer products have resulted in a shift in the gardening industry towards greener products and practices. Laws are also changing to reflect this. Witness the ban of pesticides for cosmetic use in many jurisdictions. The gardening, horticulture and landscaping industry is a multi-million dollar industry, which is shifting its practices to reflect public pressure and preferences. Even agriculture and forestry are moving in a greener direction. Everyone seems to be getting on the bandwagon of adding organic matter to soil and using more earth-friendly products.

Silent Spring

But things haven't always been so green, so to speak. The Second World War gave rise to many new chemicals which resulted in the "Better Living through Chemistry" movement of the 1950s.

Chemicals became the “silver bullet” to help us feed plants with chemical fertilizers, get rid of insects and weeds with pesticides, all to increase yields to feed a growing world population and to beautify our landscapes that would become a mainstay of society in the modern civilized world. We thought we had achieved the pinnacle of perfection and we were quite smug about it. The advent of DDT promised to eradicate the mosquito. But as we all know, the use of persistent pesticides brought about many bad things that we never imagined when we first developed and started using these pernicious and noxious products. It seemed we didn’t exercise enough foresight to imagine the havoc these would wreak on our environment and ecosystems.

Then one day in 1962, Rachel Carson published “Silent Spring”, a book destined to change the course of history. This book is certainly worth the effort of tracking down and reading. Just imagine yourself in those times and being avant-guard enough to challenge the large scale use of pesticides being developed, sold and promoted by the large chemical conglomerates of the era. In her book, Carson conveys a sense of urgency by graphically describing the destructiveness of chemical poisons on the environment and human health. She outlines the delicate balance of nature and the importance of living soils, clean water and the various organisms which contribute to establishing balance in ecosystems. She also provides alternative methods which work with nature at restoring and maintaining that ever important equilibrium. Carson created an awareness which got people thinking and questioning and eventually, in growing numbers, going back to the “old ways” of gardening and agriculture, using time-honoured techniques which respect and promote the interaction of the various organisms in ecosystems. Although we haven’t completely rid ourselves of chemicals, there is definitely a move away from their use, or most certainly a more judicious use of less persistent and less toxic substances under most circumstances.

Soil

Soil, along with water and air, supports all life on earth. We don’t think of soil as being alive, but it is. Healthy soils are teaming with all kinds of micro and macro organisms which are continually

transforming it. Dead soil can't support plant life. Can we actually get to a point where soil becomes lifeless? Unfortunately, we can. Poor soil management practices can lead to a reduction of living organisms in the soil with dire consequences.

At one time it was believed that plants only needed soil as support in which to grow and that we could simply add chemical fertilizers to keep plants growing. While this concept would eventually be perfected and successfully applied in a hydroponics context, it originally came from the nursery and greenhouse trade where plants grown in pots using soilless mixes were provided with regular applications of chemical fertilizers to keep them growing and productive. In these circumstances, pesticides have to be used to control any insects and diseases which might attack and decimate the plants. Professional plantsmen and growers started using this approach for plants grown in the ground.

I recall such an instance in the 1980s at the Central Experimental Farm Ornamental Gardens. The public display beds of annuals were regularly fertilized with chemical fertilizers such as 20-20-20, 15-30-15, or 10-52-10. High phosphate fertilizers were applied in the belief that it would promote better flowering of annuals on display. Organic material was never added as it was believed it wasn't necessary. I distinctly remember one year where a bed of zinnias were doing very poorly, in spite of the regular applications of fertilizers. They were stunted and leaves were drying and falling off. Analysis showed the plants were diseased. At one point, it was decided to do a soil test to see if there was anything lacking which could cause this problem. The soil had actually degraded to a dry powder totally devoid of organic matter. Results revealed excessively high levels of phosphorous in the soil, high enough to be toxic to plants. Unlike nitrogen, phosphorous is not mobile in soil. What the plants don't use simply accumulates where it is deposited. By contrast, nitrogen is very mobile and any excess is simply drained out of the soil and pollutes our waterways. Fertilizer salts had accumulated to the point where they were burning the roots and making the plants so unhealthy that they succumbed to diseases.

The problem beds were emptied of the diseased zinnias and I suggested adding compost which we were making in the Arboretum.

Generous amounts of compost made from leaves were added and the bed remained empty the rest of the season. The following year, zinnias were again planted and the transformation was truly amazing. The organic matter had managed to buffer the effects of the overabundance of phosphorous and the plants grew large and healthy. What was once a lifeless soil was transformed into a rich living entity full of organic matter and organisms needed to maintain healthy plants.

The Forest Primeval vs the Modern Urban Landscape

Plants in forests have survived and thrived in natural environments for millions of years without the use of fertilizers, pesticides and irrigation. Clearing of natural areas and new construction in the urban and suburban landscapes represents the extreme of soil and plant disturbance. Topsoil and vegetation removal and extensive disturbance associated with site preparation and equipment operation in developing urban landscapes results in soil compaction, scarification and erosion, leaving behind poor quality soils incapable of sustaining healthy plant communities. High input of inorganic fertilizers and irrigation is required to keep plants alive and growing. This kind of growing environment can be stressful to newly planted trees, shrubs and perennials. What these soils lack is that “living” quality of soils found in the forest primeval environment.

Living soils include a myriad of beneficial bacteria, fungi, protozoa, nematodes, and a wide variety of soil arthropods and worms. Their numbers in healthy soils are nothing less than staggering. A teaspoon of forest soil can contain miles of fungal filaments and several billion bacteria. The interaction of these organisms with plant roots is the foundation of healthy, living soils. They perform an essential role in maintaining healthy root systems, good soil structure, drought protection, salt tolerance, and protection against a wide variety of environmental extremes. As organic matter is consumed by these organisms, it is replenished on a regular basis by fallen leaves, twigs, branches and dead insects and animals. But in modern day landscapes, organic matter must be added regularly to maintain a healthy number of beneficial organisms.

Mycorrhizal Fungi

Fungi are a cornerstone of woodland ecosystems. When it comes to transforming organic matter, especially high carbon products like wood and leaves, into substances plants can use, one of the key players in this intricate web of life is fungi. When we think of fungi, we generally think of mushrooms, toadstools and conks which decompose dead trees and other vegetative matter on the forest floor in the endless cycle of soil production. These saprophytic (decomposers) fungi work tirelessly at transforming organic matter into rich soil. There is, however, another important class of fungi living in these natural environments which form mutually beneficial partnerships with plant roots. These are known as mycorrhiza (plural = mycorrhizae) or mycorrhizal fungi. Mycorrhizal fungi are the dominant organisms in undisturbed soils accounting for 60 to 80 percent of the soil microbial biomass.

Mycorrhiza (mike-o-RISE-a) is derived from the Greek word for fungus, *mykes* (in English *myco*) and *rhiza* meaning root. The symbiotic (mutually beneficial) association formed between plant roots and micorrhizae (mike-o-RISE-ee) is a world-wide phenomenon in healthy, natural soils. Micorrhizae attach themselves to plant roots and facilitate the absorption of water and nutrients to plants by increasing their surface absorption area 10 to several hundred times. In return, plants provide the fungi with essential carbohydrates for their own growth. The root-like filaments of fungi, called hyphae, attach themselves to plant roots and explore vast areas of soil much faster than normal roots. A fungal mass is known as mycelium, and can range for several miles throughout forests and form partnerships with several trees of different species. Some scientists believe mycelium are the Earth's natural Internet connecting plants together, even allowing a transfer of nutrients between different species of connected plants. In addition, their ability to respond to natural disasters and sudden changes in the environment is believed to be a testimonial to their inherent intelligence. These partnerships have been going on for millions of years. In fact, it is believed that the development of mycorrhizal symbiosis with primitive aquatic plants played a crucial role in the initial colonization of land by plants and in the "greening" of our planet.

Mycorrhizae partner with 95% of land plants and are found in a variety of ecosystems and plant communities, including wetlands, deserts, deciduous forests, tropical rainforests, high latitudes and prairies. About the only terrestrial setting in which they do not occur are where plants are absent. The discovery of mycorrhizae is attributed to a German forester in the 1880s. Much of the early research was focused on trees in forests. Soils from natural and undisturbed forest areas generally contain robust and diverse populations of mycorrhizal fungi. Since then, over 50,000 research studies have been done on mycorrhizal partnerships with plants and as a result, have established beyond a doubt the importance of these organisms in maintaining healthy plants and ecosystems.

The edible chanterelle (*Cantharellus cibarius*) forms mycorrhizal associations with both birch and pine.

The deadly fly agaric (*Amanita muscaria*) is one of the most distinctive fungi, and grows in association with birch trees.

There are two major types of mycorrhizae with which we need to concern ourselves here: Endomycorrhizae and Ectomycorrhizae. The main difference between the two types is in their method of association with roots.

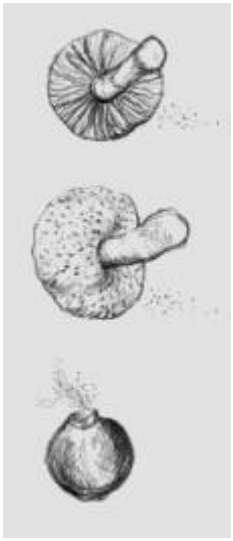
Endomycorrhizae, also known as arbuscular mycorrhizae, colonize the vast majority of plants by penetrating feeder roots and sending their filamentous hyphae into individual cells. They are very beneficial to 80% of landscape plants, including perennials, annuals, grasses, shrubs and a large number of trees such as maple, magnolia, dogwood, ash, crabapple, yew, juniper, and redbud. Reproduction is by spores formed either in roots or more commonly in soil. Thus, endomycorrhizae do not form the typical mushroom fruiting bodies that we normally associate with fungi.

Ectomycorrhizae form a net, known as a Hartig Net, which surrounds the cortex of feeder roots. Their hyphae then further penetrate the areas between the cells within the root tip. However, they do not penetrate inside the cells like the arbuscular mycorrhizae. These form associations with approximately 10% of the world's plants, primarily trees like pines, spruces, firs, Douglas firs, oaks, beeches and birches. Ectomycorrhizae form typical mushrooms found in forests and other suitable environments, and include puffballs and truffles, which are fruiting bodies growing from the mycelium to produce spores for reproduction.

An example of an ectomycorrhiza - the modifed, multi-branched rootlet
of a Scots pine is sheathed in a furry mass of fungal hyphae.

Categories of Forest Fungi		
Mycorrhizal	Endo-	*Important for most plants and some trees*
	Ecto-	*Important for many trees, e.g. conifers, oaks, beeches*
Saprophytes or Detrivores		*Litter decomposers*
Pathogenic/parasitic		*Principal causes of tree death*

A gilled mushroom releasing its spores for dispersal by the wind.



Three different fungal structures for releasing spores – gills (top), pores (centre) and puffballs (bottom).

Benefits of Mycorrhizae

Since mycorrhizal partnerships are symbiotic, both plant and fungus benefit from the association. Fungi don't photosynthesize to produce their own food like plants do, so they need to obtain it from other sources. In this way, they are more like insects and animals as they feed on other organisms to sustain themselves. However, mycorrhizal fungi have developed a unique approach by obtaining sustenance from plants and in return keep their hosts not only alive, but healthy and thriving to ensure a food supply for long periods of time.

Improved Water Absorption – The hyphae of mycorrhizal fungi can penetrate much smaller areas compared to roots and travel much farther, absorbing and storing water for use by the host plant. This ability makes the plant more resistant to drought stress and helps the plant develop a more extensive root system.

Improved Nutrient Availability – Mycorrhizae excrete powerful enzymes which can break down hard to absorb nutrients like phosphorous, iron and other micronutrients, making these more readily available to the host plant. They also break down organic matter into compounds like nitrogen, which can be readily absorbed by plants. Trees and plants with flourishing mycorrhizal colonies are significantly more effective at extracting nutrients from the soil, reducing or even eliminating the need to apply additional fertilizers,

as long as organic matter is replenished on a regular basis. These fungi may also selectively alter the soil pH to suit nutrient availability and make a more hospitable environment for plants.

Increased Resistance to Insect Pests and Diseases – Mycorrhizae have antibiotic properties which reduce the ability of certain diseases to infect plants. Ectomycorrhizae form an actual physical barrier around tree roots that make it harder for pathogens (diseases) to infect roots. One type of ectomycorrhizae has been found to produce chemicals that lure and kill springtails, a tiny insect which feeds on feeder roots, and use the nitrogen from the springtail to feed its host plant.

Improved Soil Quality – Mycorrhizal fungi improve soil structure by producing humic compounds and organic polysaccharides that act like glue, binding soil particles into aggregates, thus improving soil porosity, aeration, and water movement through soil. This promotes root growth and distribution.

Increased Transplant Survival – Plants that are inoculated with mycorrhizae at transplant time have an increased survival rate due to a more highly developed root system and the increased absorbing capacity of the mycorrhiza. The improved root system of inoculated plants can result in an increase in total root surface area up to 18 times that of an uninoculated plant.

Improved Health, Immune Systems and Growth – Plants that develop mycorrhizal associations are generally healthier, have stronger immune systems, and grow more quickly than non-mycorrhizal plants.

Red maples treated with a granular mycorrhizal inoculant at outplanting survived summer drought

Non-treated red maples planted adjacent to the treated maples did not survive

Threats to Mycorrhizae

Disturbance to soils encountered in large scale operations where heavy machinery is used can result in harmful soil compaction. Also, topsoil removal from construction projects reduces the overall quality of soils and removes existing mycorrhizae and discourages the colonization of new ones into the area. Overuse of chemical fertilizers and pesticides, often encountered in intensive agriculture and forestry, as well as in intensive turfgrass management, can suppress the development of mycorrhizae. Overuse of phosphate fertilizers can destroy and discourage mycorrhizal formation, especially if organic matter isn't replenished. Excess nitrogen, whether from fertilizer use or atmospheric pollution, can adversely affect mycorrhizae as well.

Comparison of characteristics of undisturbed forest soil and disturbed, intensively managed urban soils

Undisturbed Forest Soil	Disturbed, Intensively Managed Urban Soil
Loose, well aggregated	Compacted
Low to moderate fertility	High fertility, artificially maintained
Fungal dominated	Bacteria dominated
High levels of mycorrhizae	Low levels of mycorrhizae
Seasonal moisture inputs, well drained	High levels of irrigation, poorly drained
High levels of organic matter	Low levels of organic matter
Low, stable pH and temperature	High, variable pH and temperature
Low levels of surface erosion	High levels of surface erosion
Low salt concentration	High salt concentration
Low level of soil borne diseases	High levels of soil borne diseases

The Role of Mycorrhizae in Woodland Conservation and Restoration

Many foresters are working hand in hand with ecologists, soil scientists and mycologists (mushroom scientists) in an effort to maintain soil integrity in forests. This translates into healthy forests. Mycorrhizae are so crucial to tree health, that the practice of inoculating the soil with mycorrhizae at planting time is becoming increasingly common. Because of their ability to buffer the effects of toxic concentrations of minerals in contaminated sites, such as former mining sites, mycorrhizae are used to inoculate newly planted trees to ensure their survival. There is no doubt that the restoration of wild, native woodland could not take place without these complex, fascinating and hidden partnerships.

The Use of Mycorrhizae in Gardening and Landscaping

Commercial formulations of mycorrhizal inoculants are now available for home gardeners and commercial landscapers. Many landscape professionals are already incorporating their use on a regular basis as a sound business investment. Inoculums containing mixtures of different species often give the best results. These come in granular, liquid, powder or tablet forms which, when applied at planting time or as a drench after planting, can provide plants with all the benefits of mycorrhizal partnerships. The important thing is to get the mycorrhizal propagules near the root systems as chemicals produced by active feeder roots cause mycorrhizal propagules to become active and grow. While mycorrhizal inoculation is beneficial in all situations, it is particularly effective on disturbed and stressful sites.

Pine tree on the left was treated with a granular mycorrhizal inoculant at outplanting and pine on the right was not treated.

How Mushrooms Can Help Save the World

Mycologist Paul Stamets and his team of researchers are engaged in cutting edge research which is demonstrating amazing potential in the areas of human health and environmental remediation. Following are some areas of research being explored.

1. Human Health – some mushrooms have demonstrated abilities to enhance the human immune system by producing a slew of natural and powerful antibiotics; preliminary research by the National Institute of Health in the U.S. has shown that some mushrooms can produce enzymes which are effective at destroying human viruses; promising research has been carried

out in the areas of smallpox and various strains of flu viruses; research and trials are under way with certain mushrooms in the treatment of HIV and AIDS.

2. Mycofiltration – mycelia of specific mushrooms have demonstrated incredible abilities as biological filters in treating hazardous animal wastes from farming operations close to waterways. The establishment of diverse and species rich riparian environments near waterways, including mycelium, trees, grasses and other plants can provide a sustainable buffer zone against contaminants entering waterways.
3. Mycoremediation – research has shown that mycelium produces powerful enzymes capable of breaking apart hydrocarbons, the base structure common to oils, petroleum products, pesticides, PCBs, and many other pollutants; in a joint project with the Washington State Department of Transportation, Stamets demonstrated that a specific strain of Oyster mushroom was capable of breaking down heavy oil in a pile of soil after just four weeks; analyses showed that more than 95% of many of the PAH (polycyclic aromatic hydrocarbons) were destroyed, reduced to non-toxic compounds, and the mushrooms were also free of any petroleum products; after eight weeks, the mushrooms rotted, attracting flies and other insects; these attracted birds which colonized the pile with plant seeds which then germinated. The pile was teaming with life, while two other piles, one treated with bacteria and another with chemicals, to compare effectiveness in dealing with the oil waste, remained contaminated.
4. Mycoremediation of toxic organisms – When mycelia encounter *E. coli* in soils, they are capable of changing their chemical make-up to effectively destroy and consume the offending bacteria; this same ability has been used in experiments to destroy biological and chemical warfare agents.

Officials from the U.S. Bioterrorism Institute and the Department of Defense (DOD) Bioshield Program, which was set up to find new medicines from unexpected sources, are extremely interested in some of Stamets' discoveries and have contracted with him to conduct research into the medicinal properties of many mushrooms. Since Stamets works primarily with mushrooms from old growth

forests in the northwestern U.S., he is putting forward the argument that we should save old growth forests in the interest of national defence.

For more in-depth information on Paul Stamets' research with mushrooms in the area of human health and environmental remediation, you can listen to an interview and read the transcript of this fascinating interview at:
http://personallifemedia.com/podcasts/224-living-green/episodes/2914-paul-stamets-fungal-intelligence-and-the-21st-psychedelic-journey-how-mushrooms-can-help-save-the-world-in-our-11th-hour-edition-

A similar video of Paul Stamets at a conference talking about how mushrooms can help save the world can be viewed at:
http://www.youtube.com/watch?v=XI5frPV58tY

Conclusion

I have always felt and believed that a healthy, living soil is capable of many great things, including healing itself of all the injuries we can inflict upon it. I have always felt and believed that a healthy living soil, given time, can remedy itself of accumulations of toxic materials resulting from overuse of pesticides. But all of this hinges on one thing – organic matter. Organic matter gives soil that magical "life" which can do all of the great things described. What is particularly satisfying to me, is that this has been going on for millions of years, and will continue to go on, whether we choose to be part of it or not. The choice is ours. Let's hope we can put our egos aside and choose to work with other intelligent life forms to keep this beautiful planet inhabitable.