ORGANIC MATTER IN SOIL

The presence of organic matter has long been recognized as an essential component of a highly productive soil. Since ancient times, farmers worked for good tilth in the soil; that is, the combined soil characteristics of good aeration, structure, drainage, moisture-holding capacity, buffering capacity, and nutrient availability. All these characteristics are directly affected by the amount of organic matter in the soil. The introduction, use of, and reliance on commercial fertilizers have temporarily shadowed these virtues. Increasing pressures from the population, however, have prompted reinstatement and modification of former waste management techniques. Demands for higher productivity from forest nurseries are increasing. Nursery managers must understand the role of organic matter on the total soil system, and thereby its role in plant growth, to maintain present levels of nursery production and especially to increase production of high quality trees.

Because decomposition is continual, organic material must be added and incorporated periodically. In forest nurseries, the reduction of organic material is hastened by continuous weeding and cultivation, artificial irrigation, and additions of commercial fertilizer that promote microbial activity and rapid decomposition of organic material (Wilde and Patzer 1940). In some other forms of agriculture, benefit is gained from leaving roots of crops that add organic material. But nursery production does not have this added benefit. Also, soil organic material adheres to roots and is removed with tree seedlings.

The addition of organic matter affects the physical, chemical, and biological properties of the soil. These properties are interrelated but will be discussed separately

IMPACTS ON PHYSICAL PROPERTIES

Nursery operations including tilling, preparing seedbeds, and lifting are easier and more effective when the humus level is high. Often under intensive management, the humus level is reduced because humus decomposes and is utilized more rapidly than normal. Furthermore, when seedlings are lifted, some humus is removed with the plant and is not returned to the seedbed.

SOIL STRUCTURE

Humus has a profound effect on the soil structure, the aggregation of soil particles or the way the particles fit together. Good tilth is synonymous with crumbly, granular structure. The crumbs, aggregates, or peds are held together by bonds of organic compounds and clay. Frequent additions of easily decomposable organic material provide necessary organic compounds that bind soil particles into peds (Figure 1). Aggregation by humus reduces surface crusting, enabling water to enter the soil more easily (infiltrate) and percolate downward through the soil (permeate) thus improving drainage and ease of root penetration.

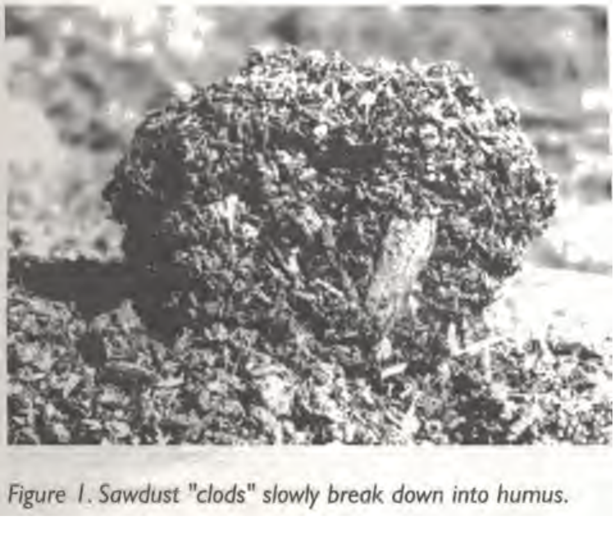
Figure 1. Sawdust "clods" slowly break down into humus.

Tilth is improved by green manuring, especially in finer-textured soil. This occurs by the interaction of factors associated with improved aggregation of the fine clay particles and in a lower bulk density (Allison 1973). Sandy soil is benefited by green manuring through increased moisture-holding capacity and increased availability of nutrients. One of the chief benefits to sandy soil is an increase in cation exchange capacity. All these benefits are realized soon after the green manure crop is incorporated into the soil. Also associated are benefits in water infiltration and retention, in drainage, and in water use efficiency (Allison 1973).

BULK DENSITY

Nursery operations usually require long-term use of heavy machinery at times when soil moisture is high; this compacts the soil. Repeated compaction leaves many nurseries with hardpans, which restrict the root growth of young seedlings and flow of water through the soil. Addition of organic material, combined with ripping and wrenching practices, may mitigate compaction by reducing bulk density and increasing the formation of soil structure.

WATER HOLDING CAPACITY

The water-holding capacity of soil is greatly increased with the addition of organic matter (Table 1). Humus acts like a sponge in the soil by absorbing water readily. Thus, additions of organic matter to coarse-textured soils can increase the amount of water stored for plant use and thereby reduce the need for irrigation. The capacity to store water is improved by water-absorbing materials such as peat moss, redwood shavings, and vermiculite and to a lesser extent by larger wood chips, fir bark, or rice hulls (Warneke and Richards 1974).

Table 1 - Relation of soils and organic matter to water-holding capacity and availability of soil water

Soils, organic matter, and their mixtures	Water-holding capacity[1]e	Moisture equivalent[1]	Wilting point	Available water	
				Percent	Percent of water-holding capacity
		Percent			
Soil:					
Clay loam	44.3	20.2	7.1	13.1	30
Quartz sand	28.3	1.4	.57	.83	29
Organic matter:					
Moss peat	1,057.0	166.0	82.3	83.7	8
Reed peat	289.0	110.0	70.7	39.3	14
Mixtures:					
1 : 1, clay loam : moss peat	114.0	31.0	14.5	16.5	14
4 : 1, clay loam : moss peat	57.4	21.6	8.5	13.1	23
1 : 1, quartz sand : moss peat	89.1	12.7	5.2	7.5	8
4 : 1, quartz sand : moss peat	47.8	5.6	1.8	3.8	8

[1] The values shown represent water by weight rather than by volume.

Source: Bollen (1969).

WATER AVAILABILITY

Where organic amendments have fully decomposed into humus, more water is available to plants through improved aggregation. Where organic additions are not fully decomposed, infiltration and aeration are improved, but there may be slightly less available water. The exception is with coarse-textured soils (Bollen 1969). Table 1 shows little increase in available water with increased amounts of peat moss to clay soil but considerably more available with increased peat to a quartz sand.

Water relations are usually improved under summer mulches because infiltration increases and surface evaporation decreases. These relations, however, create problems in wet climates with excess moisture. By lowering evaporation in surface soil, mulch also reduces the content of soluble salt in surface soil during the summer (Robert 1978).

EROSION

Organic matter helps reduce soil erosion by increasing the moisture-holding capacity of soil, improving infiltration, permeability, and drainage and reducing surface runoff. Also, the improved structural aggregation by humus reduces the potential for individual particles of soil to be loosened by raindrops and subsequently carried away by moving water.

Keeping the soil covered with vegetation is critical to erosion control. Green manure is often used as a cover crop for this purpose if it can be managed between crop rotations with little disturbance to the soil. Sod crops are preferable for maximum protection. In Ontario, Canada, cover crops such as rye and oats are used to prevent surface erosion by wind and water (Armson and Sadreika 1974). Mulch protects seeds or seedlings from wind and water erosion, prevents puddling and crusting of soil, and minimizes evaporation of water from surface soil (Armson and Sadreika 1974).

TEMPERATURE

Organic matter effectively insulates the soil against sudden changes in heat and cold. Mulches have been recognized to reduce the rate of heat exchanged and the total heat conducted and released from the surface of the soil (Roberts 1978). By minimizing fluctuations in temperature in the root zone of plants, mulch protects seedlings from extremes of hot and cold and reduces frost heaving. Sawdust is effectively used in Canada (van den Driessche 1969) to prevent frost heaving of young tree seedlings.

Heat capacity of a mulch refers to how much heat it will hold and depends on its water content and size of particles. For instance, peat moss holds more water than sawdust which holds more water than bark. Water is the ideal heat sink because it changes temperature very slowly. The more water an amendment holds, the more slowly it, too, will change temperature.

Insulating effects of mulch improve the distribution of roots in surface soil by improving aeration and bringing about more uniform temperatures and moisture conditions (Roberts 1978). Characteristics of the mulch such as composition, state of decomposition, size of particles, and color will determine the degree of insulation. Old mulch loses its insulating value when it becomes decomposed, wet, or compacted. Thus, the best mulch for insulation must be decay resistant.

The color of mulch material can also be important. Light colored mulches, such as most sawdust, reflect light and heat that can cause sun scald of lower leaves or needles of seedlings. Darker substances, like bark, will absorb light and heat more rapidly and also lose moisture more readily because of increased evaporation.

AERATION

Roots of plants need good aeration to absorb oxygen for growth. Soils with high bulk densities often have less pore space than those with lower bulk densities. Organic amendments tend to reduce the bulk density of soil and to increase pore space. Warneke and Richards (1974) have shown how a variety of soil amendments lowered bulk density and greatly improved permeability of soils.

The addition of polymer soil conditioners have been found to be useful in flocculating clay in soil and improving the water stability of soil aggregates. Wallace and Wallace (1990) found that plant yields increased when water-soluble polymer soil conditioners were applied together with organic matter to the soil.

The addition of organic matter to heavy soils is critical to improve aeration. Care must be taken, however, to prevent excessive additions at any one time to coarse-textured soils that may cause too much aeration and rapid drying of the soil in hot weather. Once organic materials decompose to humus, however, this is not a problem.

IMPACTS ON SOIL CHEMICAL PROPERTIES

Humus, which is a form of organic matter, serves as a reservoir of chemical elements essential to plant growth. Most soil nitrogen and phosphorus is organic. Other nutrient elements, such as sulfur, are also associated with humus.

MACRO-NUTRIENTS

As a source of nutrients, organic matter may be generally regarded as a slow-release fertilizer. Through microbial activity, essential nutrients such as nitrogen, phosphorus, and sulfur are slowly made available to plants as the organic residue is decomposed (see "Decomposition of Organic Amendments").

Organic amendments vary widely in content and availability of nutrients to plants. Table 2 summarizes the content of selected macronutrients for a variety of organic amendments. It should be noted that nutrients contained in organic amendments are not always available to

Table 2 - Content of some macronutrients in various organic amendments

Organic material	Total N (Kjeldahl)	P	K	Ca	Mg
		Percent, dry basis			
Bark					
Douglas-fir	0.12	0.011	0.11	0.52	0.01
Ponderosa pine	.12	.003	.11	.25	.01
Redwood	.11	.011	.06	.29	.00
Red alder	.73	.153	.24	1.25	.18
Sawdust:					
Douglas-fir	.04	.006	.09	.12	01
Ponderosa pine	.04	.008	.12	.16	.02
Redwood	.07	.001	.01	.20	.02
Red alder	.37	.013	.12	.18	.04
Moss peat	1.83	.030	.02	.50	.12
Farmyard manure[2]	1.6-2.8	1.4-2.3	0.3-0.4	– –	--
Sludge:					
Sewage[3]	2.0-8.0	1.5-3.0	0.2-0.8	----	-----
Mint[4]	[5]	.072	.15	----	----
Fish[6]	.04	.003	.006	---	---

____ = No data.

[1] Canadian sedge peat is often 2.4 times as high in nitrogen.

[2] Aldous (1972).

[3] Hausenbuiller (1978).

[4] Data taken from laboratory test, Oregon State University, 1979.

[5] Total N unknown; nitrate N is 0.008.

[6] Dutton, Wind River Nursery. USDA Forest Service. Personal communication. 1979 and 1980.

Source: Bollen (1969), except as otherwise note

plants. Organic material must be decomposed by micro-organisms in the soil to release the nutrients into the soil solution, making them available to plants. The physical condition of the soil is a key factor in the conversion of nutrient supplies to available forms through its influence on microbial activity.

Douglas and Magdoff (1991) looked at seven types of manures, six sewage sludges, and six composted or mixed soil amendments in an attempt to evaluate possible indicies to predict nitrogen (N) availability during decomposition. They define the total amount of N that will be potentially available in a residue amended soil as

PAN = (INORG-N + MON)soil +
(INORG-N + MON)residue

where PAN equals potentially available N and MON equals mineralizable organic N. Their findings show that it is possible to predict the fraction of organic N mineralized by indexing using the Walkley-Black N digest (Heese 1971).

C/N RATIO

All organic matter, whether added as an amendment or as green manure, is first broken down by microbial organisms (microbes). The microbes (bacteria, fungi, and actinomycetes) become active and multiply rapidly with sudden additions of organic material. If microbes do not find sufficient nitrogen in the amendment, they absorb their requirement from the soil, thereby competing with other microbes and plant roots. Immobilization of nitrogen occurs when much of the inorganic nitrogen is converted to organic forms by microbes which use the nutrients to build their tissues. Thus, most of the nitrogen is tied up (immobilized) temporarily in the microbial bodies, and little, if any, nitrogen is available to higher plants. The condition persists until most of the easily oxidizable form of nitrogen in their tissues is once again converted (mineralized) to inorganic states available to plants (nitrate and ammonium). Through this process the soil becomes temporarily richer in both nitrogen and humus (Figure 2).

The carbon-to-nitrogen (C/N) ratio is the limiting factor. When the amount of carbon is high in relation to nitrogen contained in the residue, such as in straw, bacteria will require a high amount of nitrogen to decompose the residue. Therefore, addition of amendments with a high C/N ratio will result in a temporary depletion of soil nitrogen if

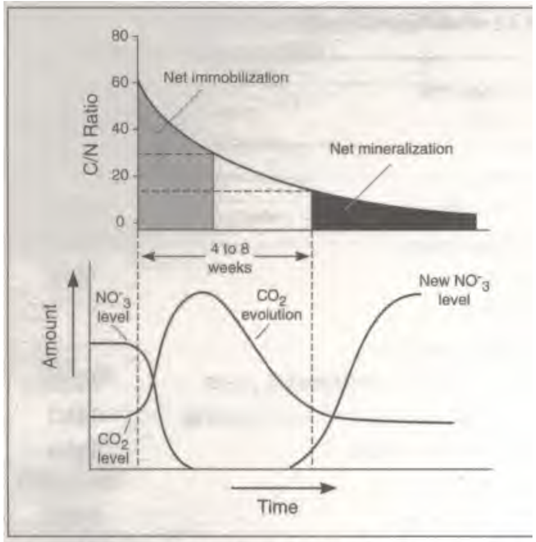

Figure 2. Changes in nitrate levels of soil during the decomposition of low-nitrogen crop residues. (From Tisdale and Nelson (1975), with permission of Macmillan Publishing Company, Inc.)

supplemental nitrogen is not added. Tables 3 and 4 summarize data, especially that of Bollen (1953,1969), on the C/N and other characteristics of various organic materials.

The C/N ratio of the added material determines the availability of nitrogen to the micro-organisms. For instance, if organic material high in carbon and low in nitrogen (high C/N ratio) is added to the soil, some pathogens are unable to infect their hosts because they lack sufficient nitrogen to sustain growth (Burke 1969). Powelson (1969) cited several cases in research when effective disease control occurred with the addition of residue having a high C/N ratio. Soils amended with mature, finely ground crop residues possessing a high C/N ratio controlled *F. solani* f. sp. *phaseoli,* the cause of pinto bean roo,t rot, when applied at a rate of 10 to 12 tons per acre. Control was nullified when 120 pounds per acre of ammonium nitrate was added (Powelson 1969).

Huber et al. (1965) list a wide variety of crop residues shown to reduce bean root rot after their incorporation. These residues include sawdust, cellulose, wheat bran, sorghum, alfalfa hay, oat straw, soybean hay, bean straw, barley straw, wheat straw, corn shucks, and pine shavings. Control was attributed to the inability of *Fusarium solani* f. sp. *phaseoli* or other pathogens to compete with micro-organisms that were rapidly immobilizing soluble nitrogen. In other words, control occurred because organisms decomposing the organic residue tied up the soil nitrogen. Residues with low C/N ratios increased bean root rot. Incorporation of residues such as tomatoes, alfalfa, lettuce, bean-seed meal, green barley, barley straw, alfalfa, or soybean straw resulted in increased severity of the disease. These residues may also contain chemical compounds that encourage disease.

The hypothesis that the C/N ratio of crop residues directly influences the control of soil-borne diseases has not been clearly proven. Materials with low C/N ratios have occasionally been reported to control soil-borne diseases. There are inconsistencies in the literature, suggesting relationships other than the C/N ratio may be involved in disease control.

Huber et al. (1965) suggest that crop residues affect severity of disease through

Table 3 - Analysis of cold-water solubles in various organic materials

Organic material	Acidity	Portion water soluble[1]	N (Kjeldahl)	C/N ratio
	pH	*Percent, by weight*		
Western redcedar:				
Bark	3.2	2.95	0.14	378:1
Wood	3.5	6.99	0.06	810:1
Redwood:				
Bark	3.2	2.35	.11	473:1
Wood	4.4	1.67	.07	753:1
Red alder:				
Bark	4.6	11.64	.72	71:1
Wood	5.8	1.43	.13	377:1
Western hemlock:				
Bark	4.1	3.95	.27	212:1
Wood	6.0	3.47	.04	1,234:1
Ponderosa pine:				
Bark	3.8	4.35	.12	422:1
Wood	4.4	2.68	.04	1,297:1
Sitka spruce:				
Bark	4.9	10.89	.41	130:1
Wood	4.1	1.27	.04	1,214:1
Douglas-fir:				
Untreated -				
Bark	3.6	5.49	.12	471:1
Wood	3.4	4.65	.04	1,268:1
Sour sawdust	2.0	12.81	.06	893:1
Moss peat	3.8	1.04	.83	58:1

[1] Total solids in 12 successive water extractions, 1:10 dilution, 24 hours each.

Source: Bollen (1969).

Table 4 - Carbon-to-nitrogen ratio of farm and forest products used as mulches and soil conditions

Organic material	C/N ratio, water—free basis	Organic material	C/N ratio, water—free basis
Alfalfa hay	18:1	Cones:	
Bent grass clippings	13:1	Douglas—fir	133:1
Fiber flax, deseeded	373:1	Sitka spruce	109:1
Corn cobs	108:1	White fir	75:1
Rice hulls	72:1	Sawdust:	
Meadow hay (rush and sedge)	43:1	Douglas—fir —	
Pea vines:		Mill run, weathered 3 years	142:1
In bloom	17:1	Mill run, weathered 2 months	623:1
Mature (less pods)	29:1	Resaw, fresh	996:1
Straw:		Resaw —	
Rye	144:1	Red alder	134:1
Wheat	373:1	Western redcedar	729:1
Leaves, weathered:		Western hemlock	1,244:1
Oak	26:1	Ponderosa pine	1,064:1
Walnut	26:1	Sitka spruce	1,030:1
Douglas—fir		Lignin (Douglas—fir):	
420—year—old tree —		Scholler	881:1
Needles	58:1	Springfield	834:1
Bark	491:1	Cedar tow (western redcedar)	750:1
Sapwood	548:1	Moss peat	58:1
Heartwood	429:1	Waste sulfite liquor	
Bark —		(8.28—percent solids)	748:1
Young	304:1	Orzan Al	15:1
Old	293:1	Sewage sludge, digested	10:1
Cork	456:1	Cannery wastes, solid offal:	
Bast	494:1	Bean	10:1
Fines	451:1	Beet	18:1
Dust	317:1	Peach	40:1
Charcoal	305:1	Pear	63:1
Cinders	86:1	Tomato	10:1
White rot	73:1	Peptone, Difco	3:1
Red rot	49:1	Brazilian water weed	11:1

[1] Waste suffite liquor. dehydrated ammonia base.

Source: Bollen (1953).

their effect on nitrification, which, in turn, determines the form of nitrogen available in the soil. Severity of *Fusarium* and *Rhizoctonia* was reduced by adding residues that increased the rate of nitrification. Conversely, residues inhibiting nitrification increased severity of disease, but they need to be incubated in the soil for longer periods before plant exposure.

CATION EXCHANGE CAPACITY

Adding organic material to soil, particularly to sandy soils, increases the soil's ability to retain nutrients and supply them to trees. The cation exchange capacity (CEC) increases proportionally with increases

Table 5 — Cation exchange capacity (CEC) of various organic materials and nursery soils

Organic material and nursery soil	Size of mesh	CEC
		Meq/100 g
Douglas—fir:		
Bark	+5	44.8
	—10+40	39.7
	—40	60.5
Wood	—10+40	39.5
	—40+100	28.2
	—100+200	15.0
Red alder:		
Bark	—10+40	40.4
Wood	—10+40	59.0
	—100+200	7.5
Ponderosa pine wood	—10+40	13.5
Wheat straw	—10	39.4
	—60	19.4
Moss peat	—10	120.6
Nursery soils, USDA Forest Service:		
Bend, Oregon (loamy sand)		[1] 7-9
Medford, Oregon (sandy loam)		8-12
Wind River, Washington ("shotty" loam)		[1] 14-40

Data on file with Donald E. Boyer.

Source: Bolien (1969). except as otherwise noted.

in organic matter. The CEC is important to plant growth by holding necessary cations such as potassium, calcium, and magnesium against loss by leaching while making them available to roots and microbes. Organic matter provides for retention of nutrient cations added to soil in the form of fertilizers. On a weight basis, the CEC of organic matter is much greater than that of clay. Leaf (1975) stated that a CEC of less than 8.0 milliequivalents per 100 grams for conifer seedlings is low and requires attention such as adding massive amounts of organic matter to correct the situation. Table 5 shows the CEC of various organic materials and nursery soils.

PH

Buffering capacity is the ability of a soil to resist change in pH. The buffering capacity will increase with an increase in clay and/or organic matter. Thus, a soil high in organic matter will not be as susceptible to sudden changes in acidity as a soil low in organic matter. This is important when considering long-term effects of various fertilizers.

Organic matter gives chemical buffering properties to the soil. This results in suppressing adverse effects of acidity or alkalinity, biocides, and to a certain extent, toxicity by heavy metals. The fact that organic matter plays a major role in adsorption of pesticides is well documented (Hance 1974, Huggenberger et al. 1973, Stevenson 1972a). The adsorption influences the rate of application, its movement through the mineral soil, phytotoxicity to species, volatility, and biodegradability. Thus, the effects of adsorption by organic matter may seem detrimental by commonly decreasing bioactivity and increasing residence time of the pesticide. On the other hand, there is the beneficial reduction of toxicity to tree seedlings. Pesticide-induced phytotoxicity is reduced proportionally by the amount of organic matter in the soil (Davey and Krause 1980). Harmful concentrations of biocides in the mineral soil can increase the mortality of seedlings, depress growth, and cause radical changes in nutrient uptake and composition of plants (Mader 1956). These changes may be accompanied by lowered resistance of seedlings to unfavorable environmental factors such as drought, frost, and insect damage. Research by Mader (1956) shows that if such toxicities from biocides are detected, incorporation of biologically active humus in the soil offers one means (perhaps the only means) to improve the growth and quality of nursery stock.

CHELATION

Some of the literature suggests that organic matter plays a considerable role in tying up metals in the form of chelate complexes. Organic chelation of toxic metals such as mercury, lead, copper, zinc, and cadmium, has been recognized (Petruzellie et al. 1978, Stevenson 1972b). Metals may form a chemically bound net with organic matter and exert a protective action on soil peds.

MICRONUTRIENTS

Little is known about micronutrient chemistry in nursery soils compared to macronutrients. It is known that practically every aspect of micronutrient chemistry is related to organic binding or chelation (Stevenson 1972b), but micronutrient deficiencies are difficult to show through standard soil or tissue analysis. Until the concentration of a particular micronutrient becomes deficient, tree seedlings do not manifest a weakened appearance. Therefore, the influence of micronutrients on tree seedlings remains difficult to detect (Iyer and Wilde 1974). Vector analysis (Haase and Rose 1995) is one method for examining the overall nutrient balance in plants, and hence soil. The technique allows for simultaneous comparison of plant growth, nutrient concentration and nutrient content in an integrated graphic format and aids in diagnosing deficiencies which may be visually unapparent.

IMPACTS ON BIOLOGICAL PROPERITIES

MICROBIAL ACTIVITY

Organic material is the critical energy source for both macro- and microorganisms. The initial decomposers, such as bacteria, actinomycetes, and fungi, depend on organic material to survive. The number and diversity of these first-level consumers are important to the overall balance of the microenvironment. There must be a balance between the beneficial and pathogenic microorganisms for plants to be healthy. If the humus level is low and organic material is not periodically added to a soil, the decomposer organisms will not be present in large numbers. Pathogenic micro-organisms, once introduced, will not be forced to compete in a diverse community of other micro-organisms, will have fewer natural predators, and may cause more damage than if they were present in a more stable community. Many microbiologists consider a high diversity of species indicative of high stability of the organism community (Dindal 1978).

The decomposition zone of mulch is the point of contact between the mulch and mineral soil. If the mulch is not eventually incorporated into the soil, decomposition proceeds slowly and the need for supplemental nitrogen is low. In soil amendments, only the portion that is water soluble is available for microbial decomposition. The rest, in the form of lignocellulose, is not readily available to microbes. For example, since only 5-10 percent of the bark used as mulch is water soluble, it is only that portion which is accessible for microbial attack (Bollen 1969).

MYCORRHIZAE

Adequate development of mycorrhizae is critical for proper growth and development of seedlings. Mycorrhizae improve the availability and absorption of nutrients, and protect delicate absorbing root tissue from attack by various soil pathogens (Marx 1973, Marx and Davey 1969, Stack and Sinclair 1975, Zak 1964). Mycorrhizae also benefit seedling growth by producing growth regulators (Slankis 1973) and protecting roots from soil phytotoxins (Zak 1971). Diversity of mycorrhizal types and their various ecological adaptability are important to tree growth (Trappe 1977) and establishment in plantations (Marx 1980). Establishment and maintenance of populations of desirable mycorrhizal fungi is directly influenced by management of soil organic matter.

WEED RESISTANCE

As a weed control, mulch is reported to reduce hand weeding by 60-90 percent and to stimulate growth of transplants (Aldhous 1972). Mulches such as bark applied 8-10 inches thick on orchard soils should give long-term weed control for about 10 years (Bollen 1969). This practice also has the added advantages of retaining soil moisture, eliminating cultivation, and enabling year-round use of orchard equipment. Thick mulch may benefit tree nurseries with transplants; it may, however, smother smaller seedlings.

Land left barren between rotations is more susceptible to weed infestation than if covered by a green manure. Irrigation of the green manure crop, on the other hand, may encourage weed germination. Thus, the effectiveness of green manure as a weed control is unclear. Many nurseries in England (Aldhous 1972) use fallowing to reduce weeds by frequent shallow cultivation. But the detrimental effect of increased cultivation on physical and chemical characteristics of soil must be considered.

DISEASE RESISTANCE

The concept that a healthy microenvironment gives rise to healthier plants is supported by evidence of tree seedlings' resistance to disease in different locations. Field plantations of young seedlings, for instance, do not exhibit the susceptibility to *Fusarium* sp. that nursery seedlings show. One possible explanation for this is that nursery soils are generally low in organic matter and have deficient microbial populations. Without adequate numbers of beneficial micro-organisms, such as mycorrhizal fungi, the nursery seedling has less chance of healthy growth than a seedling started in forest soil which, by nature of continual organic additions, has a rich, balanced microenvironment.

Evaluation of the effects of organic amendments on plant diseases is an extremely complex study of microbial ecology. Intricate interrelationships are involved between host species, mycorrhizal associations, pathogenic organisms, and presence of exudates and antibiotics associated with decomposition. Environmental factors of the rhizosphere, such as aeration, temperature, moisture and pH, greatly influence microbial interactions. Evidence of pathogenic response to organic amendments is cited for a number of crops because (1) little information is available regarding diseases of conifer seedlings and the effect of organic amendments on the diseases found in forest nurseries and (2) many disease organisms have a wide range of hosts.

Fungi, bacteria, actinomycetes, viruses, and nematodes cause a wide variety of plant disease. Lack of knowledge of the interrelationships between soil microflora contributes to frustration surrounding biological disease control. Antagonistic effects of some micro-organisms and/or associated antibiotics have been observed, although not. consistently. These effects may be encouraged or suppressed with addition of organic matter. Damping-off in conifers has sometimes been reduied with bacterial inoculations. Some bacteria, actinomycetes, and fungi isolated from seedlings act antagonistically towards virulent pathogens such as *Phytophthora cactorum*, *Pythium debarynum*, and *Rhizoctonia solani* (Vaartzja and Salisbury 1965). Antagonistic effects of antibiotics produced by *Penicillium* and *Streptomyces* or other microbes have been studied. Common effects exerted by isolates tested by Vaartzja and Salisbury (1965) on other fungi (species unknown) are given in Table 6. These tests indicate inhibition without death as the most common type of antagonism in the interactions of soil fungi. Antagonism may be partially caused by competition for nutrients in addition to antibiotic effects associated with *Trichoderma* spp., *Penicillium* spp., *Streptomyces* spp., and *Bacterium* spp. Strong antagonism was also seen in a *Bacterium* spp. isolated as an associate of a nematode, further illustrating the complexity of microbial interaction in soil. Antibiotic effects from bacteria appear to be important in microbiological control of potato scab, onion pink rot, *Fusarium* and *Rhizoctonia* root rot of beans, and *Typhula* snowmold of wheat (Burke 1969).

Table 6 — Common effects of isolates of fungi on other fungi in cornmeal agar dishes

Isolate	*Antagonistic effect from a distance*	*Stoppage of growth on contact*	*Lytic effects observed after contact*
Aphanomyces spp.		x	
Armillaria mellea	x	x	x
Aureobasidium pullulans		x	
Bacterium sp.	x		
Basidiomycetes[1]			x
Cephalosporium spp.		x	
Cylindrocarpon spp.		x	x
Epicoccum nigrum	x	x	
Fusarium acuminaturn	x	x	
Fusarium equiseti		x	
Fusarium oxsporum		x	
Fusarium oxsporum var. *redolens*	x		
Fusarium sporotrichoides	x	x	
Gliocladium spp.		x	x
Penicillium spp.	x	x	
Phoma spp.	x	x	
Phytophthora cactorum		x	
Phythium debaryanum		x	
Pythium ultimum		x	
Russula spp.		x	x
Streptomyces spp.	x		x
Suillus granulatus	x		
Thielaviopsis basicola		x	
Trichoderma spp.	x	x	
Trichoderma viride	x	x	

[1] *2 isolates.*

Source: Vaartaja and Salisbury (1965).

Mutitu and Mukunya (1988) demonstrated that high levels of soil amendment with coffee hulls (2:1 w/w soil:coffee hulls) effectively controlled *Fusarium*. However, these high levels also contributed to a nitrogen deficiency. Lower amendment levels also reduced the disease significantly but not completely.

Beneficial effects of mycorrhizal associations with plants have already been discussed briefly. Zak (1964) and Marx (1973) suggested that mycorrhizal fungi protect delicate root tissue from parasitic fungi by (1) utilizing surplus carbohydrates and thus reducing attractiveness of roots to pathogens, (2) serving as a physical barrier to infection, (3) secreting antibiotics, and (4) favoring, along with the root, protective organisms in the rhizosphere. Most forest nurseries manage for the development of certain mycorrhizae that may aid seedlings in growth, nutrient uptake, protection against extremes in drought and tempera tures, and/or protection against certain root pathogens. Delay in mycorrhizal formation occurs after fumigation. Sinclair (1974a) observed that potential opportunities for manipulating mycorrhizal fungi in previously fumigated soil exist during the first few weeks of seedling growth, before root systems are colonized by indigenous fungi. Nitrogen fertilizers, especially if applied in excessive amounts, can suppress the formation of mycorrhizae (Sinclair 1974b).

Nitrogen has been found to have an important effect on soil fungi (Huber et al. 1965, Smiley et al. 1970, 1972). The form of nitrogen (nitrate or ammonium) has an effect on severity of disease (Hornby and Goring 1972, Huber et al. 1965, Smiley and Cook 1973). The same form of nitrogen may have a suppressing effect on one pathogenic fungus and a stimulating effect on another. For example, the nitrate form of nitrogen has been found to decrease the severity of disease caused by *Fusarium*, *Rhizoctonia*, and *Aphanomyces*, whereas the ammonium form favors these diseases (Burke 1969, Huber et al. 1965, Smiley et al. 1970, 1972). Conversely, ammonium nitrogen reduces severity of *Verticillium* wilt of potatoes and take-all disease of wheat, but nitrate trogen will increase their severity.

The method and timing of nitrogen application has been shown to affect pathogenicity. Smiley and Cook (1973) found that the best control of wheat take-all disease caused by *Ophiobolus graminis* occurred when ammonium sulfate was mixed into the tilled layer rather than broadcast. Timing of the nitrogen application as a fertilizer or an amendment may affect the response of disease. Spring applications of ammonia nitrogen have resulted in increased severity of root rot of wheat, whereas spring application of nitrate nitrogen has no effect. If ammonium nitrogen is added in the early fall, when rapid soil nitrification occurs, it has no effect on the severity of disease. The effect of the specific form of nitrogen is not necessarily reflected in pathogenic population. Instead, the nitrogen form may change host resistance, activity of the pathogen, enzyme production, germination of chlamydospores (fruiting bodies of fungi) and/or other factors (Huber and Watson 1972).

Additions of organic residues or green manure will encourage saprophytic micro-organisms necessary for decomposition. The stimulated population of nonpathogenic saprophytes may compete for food, produce antibiotics, and thus may have some effect on pathogenic microbes. The organic amendment may also have a beneficial effect on the resistance of the host plant by slowly releasing nutrients available to the plant (Allison 1973). In addition, the effect of the organic material on physical and chemical soil characteristics will influence the dynamics of microbes.

Antibiosis refers to the microbial production of metabolites such as alcohols, acids, or specific antibiotics that create an unfavorable environment for other microflora (Weinhold 1969).

A long-term experiment tested cover crops of soybeans and barley that were incorporated in soil 3-5 months before potatoes were planted. The soybean cover crop and green manure completely prevented buildup of potato scab, but the barley cover crop and green manure nearly doubled the incidence of scab. The difference was attributed to an antibiotic effect of a bacterium stimulated by soybean growth (Weinhold 1969).

Bark has been used at rates of about 13 tons per acre to control *Fusarium* wilt of the Chinese yam (Hoitink 1980). Composted bark has also shown a suppressing effect on *Fusarium* wilt of chrysanthemums, whereas peat did not effect a change. Both woodshavings and urea have been found to increase the number of soil fungi. *Trichoderma* spp. were increased by additions of urea but not by woodshavings mixed with soil. *Trichoderma viride* is common in forest soil and appears antagonistic toward *Phellinus weirii* (Nelson 1972). Trappe (1971) also noted effects of alder as a biological control for *Phellinus* spp.

Wheat straw has shown a depressive effect on pathogenicity of *Rhizoctonia.* This may be because of the nitrogen starvation of the mycelium brought about by the saprophytes multiplying on the residue. The increase in CO, from increased respiration of the saprophytes may also contribute to the depressive effect on pathogens. Isolates of *Rhizoctonia* spp. are known to differ in their sensitivity to concentrations of CO, (Patrick and Toussoun 1970). The pathogenic phase of *Rhizoctonia* appears more sensitive to CO_2 than the resting phase (Papavizas and Davey 1962).

Several rotation and cover crops are used to control severity of disease. Corn proved more effective when used in rotation to control *Cylindrocladium scoparium* than an 8-year fallow. Corn has also been used to suppress *Verticillium* spp. in peppermint, whereas a soybean cover increased incidence of this disease because soybean is a susceptible host (Theis and Patton 1970).

Growing cover crops of flax or Sudangrass in conifer nurseries in Wisconsin has been effective in controlling root rot disease, as previously discussed. Iyer (1979) recently discovered adverse effects from using sorghum-Sudangrass mixture reflected in mortality and poor growth of seedlings. Harmful effects have not been observed in the South. An estimate of about 75-80 percent of all nurseries in the South use sorghum-Sudangrass as a cover crop. Decomposition of sorghum-Sudan hybrids may release small amounts of cyanide, which help control root pathogens. The detrimental effect of cyanide on seedlings and mycorrhizal fungi is reduced by allowing ample time for decomposition (Davey and Krause 1980). Thus, the difference in the effect of this cover crop between the northern and southern nurseries is probably the result of differences in climate (soil temperature and moisture) and subsequent decomposition.

Barley straw is considered one of the best crop amendments for reducing incidence of *Rhizoctonia* spp. (Davey and Krause 1980). There are several examples of crops that may show one effect during decomposition and another effect after rotation.

Phytotoxic compounds have been obtained from residues of barley, rye, wheat, Sudangrass, vetch, broccoli, and broadbean under natural decomposition (Toussoun 1969). Linderman (1970) observed that decomposition of barley under waterlogged conditions resulted in phytotoxic compounds in water extracts. These same phytotoxic components of the extracts (organic acids) were also found in field-decomposed barley, soybean, cowpea, and cotton. The tests implied that these aromatic acids occur in nature following decomposition of a diverse variety of plants under wet conditions.

Other tests have shown that water extracts of some plant residues were phytotoxic to seedlings of several crop plants. Among the most phytotoxic were residues from sugar beets, potatoes, alfalfa, green soybeans, peas, beans, and red clover. Other phytotoxic compounds have been found in water extracts from oat straw, timothy hay, stalks of corn and sorghum, and bromegrass (Patrick and Toussoun 1970). Green residues of plants were proven more phytotoxic than mature residues of crop plants. Obviously, many of the above crops have appeared satisfactory when used as a green manure crop or amendment as long as decomposition was allowed to occur for at least one month in a warm, well-aerated soil before sowing of subsequent crop.

Stimulation of pathogenic fungi has been observed when phytotoxins are present. This appears to be brought about by nutrients present in decomposing residues rather than by phytotoxins themselves. Toussoun (1969) suggests a two-fold effect caused by residues in stimulating the pathogen: (1) production of phytotoxins may increase exudation of host cells without causing any visible symptoms, and (2) phytotoxins may weaken host tissues, making them susceptible to attack by normally innocuous soil inhabitants.

NEMATODE RESISTANCE

Rodriquez-Kabana and Morgan-Jones (1987) re-examined the value of organic amendments in soil due to the loss of key nematicides in agriculture. They note that "the most effective amendments are those with narrow C:N ratios and high protein or amine type N content." They suggest that chitinous amendments show promise against nematodes. It is also possible to modify amendments by inoculating them with specific microbial species. Their review showed that this research area has many complex unknowns and using amendments to control nematodes and disease is difficult.

FAUNA

Faunal organisms, such as earthworms, millipedes, and beetles (second- and third-level consumers) are similarly affected by soil organic matter. As predators and carriers of bacteria, molds, and actinomycetes, they also have a key role in a stable soil environment. In addition to keeping the number of micro-organisms in check, fauna are also important agents in producing good soil structure. The extensive channels they construct help loosen the soil and improve drainage and aeration. Soil fauna can flourish only in soils which have organic matter.