Nursery Soil Management-Organic Amendments

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Abstract-In von Carlowitz' book of 1713 on economic silviculture, he devotes a full chapter to nurseries. He discusses the best soil for a nursery, how the soil is treated and prepared for sowing, and the favorability of using lots of organic matter. Thus, our present topic is hardly new. However, there is considerable new information that will help us to a better understanding of the dynamics of organic matter in soil. Recently it has been shown that some of the most active and important organic matter is soluble. It breaks down very rapidly, however, so it must be continuously replaced. Organic matter maintenance is a bother but it is essential to the production of high quality grade one seedlings. It even makes economic sense.

The roles of organic matter in the physical, chemical, and biological aspects of nursery soil management are discussed in this review. The impact of soil organic matter on air and water movement into and out of the soil, the water-holding capacity, soil compaction and bulk density, and ease of root penetration are all physical aspects. The dynamics of nutrients in the soil, both immobilization and mineralization, the components of acidity (both the pH value and exchangeable aluminum), and the cation exchange capacity are the important chemical aspects. The enhancement of mycorrhiza formation and function and the suppression of soil-borne pests, including disease organisms, nematodes, insects, and some weeds are parts of the biological factors. These are all discussed in terms of improved seedling quality.

INTRODUCTION

Forest nurseries are hardly a new idea and stressing the importance of organic matter management in nursery soil is almost as old. In von Carlowitz' book of 1713 on economic silviculture, he devotes a full chapter to nurseries. In it he discusses the best soil for a nursery, how the soil is treated and prepared for sowing, and the use of lots of organic matter is favored. He discusses what to take into account when planting hardwoods rather than conifers. However, we have progressed some since 1713. Evidence of this is contained in his discussion of planting seeds of mixed species together in the seedbed. The final section in the chapter is called "The great benefit of nurseries." Certainly, we can all relate to that idea.

After the development of mineral fertilizers, the use of organic matter in soil management was considered unnecessary for a few years. Then it became apparent that organic matter is responsible for numerous functions in the soil other than simply serving as a source of nutrients. This was cause for a redefining of the role of organic matter and its value in soil management.

Fifty years ago, S. A. Wilde (1946) called organic matter the soul of the soil. That may be a bit flowery but it does suggest the importance of organic matter. However, we must be aware that organic matter is not the only important constituent of soil. This was called to our attention by Phil Wakeley (1954) who said, "So enthusiastically is soil organic matter regarded by many that there is danger of its being expected to cure ills with which it has no connection ...."

Very recently, Fisher (1995) posed some important questions regarding sod organic matter. They included; "..is soil organic matter an important determinant of soil quality, and if it is, why are formal relationships between soil organic matter and soil quality so poor?"

There is only a poor relationship between total soil organic carbon and tree growth (Fisher 1995). This is probably because of a large difference between total and active C. "In mineral soils, the amount of active organic C, that which is in solution or exchangeable at any one time is less than I% of the total organic C..." Thus, large changes can take place in the active fraction without being detectable in the total organic C. "There may be a statistically significant relation between tree growth and some particular fraction of soil C, but we are yet to explain that relationship" (Fisher 1995).
After posing these and other tough questions, Fisher discusses them at length. Finally, after looking at some of what is known, as well as what is not known, he concludes that "Soil organic matter is the fuel that runs the soil's engine" (Fisher 1995). With this cautious but optimistic background, we will undertake a discussion of nursery soil organic matter management and its impact on important soil properties and eventually, of course, on seedling growth and quality.

Before we get down to the particulars, we need to define soil organic matter. This can be done from the philosophical to the very practical point of view. There is a lack of complete unanimity of definition, but in general, ideas are quite close. There are three basic components to soil organic matter. They include:

1) live plant and animal tissues and microbes in soil which are easily identifiable and are starting to be humified,
2) plant, animal, and microbial tissues in various stages of decomposition and which are difficult to identify, and
3) fully humified material whose origin is essentially impossible to detect (Davey and Krause 1980, Davey 1984).

From the totally practical point of view, soil organic matter is any organic material In a soil sample that we submit for analysis which will pass through the sieve that the lab uses [commonly the holes in the sieve are about 1/8th inch (2 mm)]. Anything larger than that ends up in the trash. Because of this fact, recently applied bark or sawdust frequently does not appear to have had an effect the soil organic matter content.

The study of organic matter decomposition and humification was first quantified by S. A. Waksman and associates (Waksman 1929; 1936; Waksman and Tenney 1927). The 1927 report discussed in detail the decomposition of our favorite winter cover crop-- rye.

On a world-wide basis the amount of C in decaying organic mater and fully humified soil organic matter appears to exceed the amount of C in live vegetation by at least factor of two (Bouman and Leemans 1995).

The addition of organic matter to soils can affect the cycling of nutrients through its effects on the physical, chemical, and biological properties of those soils (Johnson 1995). Thus, organic matter is shown to be involved in nearly all aspects of soil processes.

In these introductory remarks, we have seen soil organic matter go from a position of being overly important to being of little importance to the present middle ground where we realize that it is important In soil management but it is only one of several important aspects in nursery soil management. With these thoughts in mind, we will now undertake a discussion of the various roles and effects of soil organic matter.

PHYSICAL PROPERTIES AND EFFECTS

Soil organic matter occurs in the solid, colloidal, and soluble states. The surface area of the colloidal material is extremely large and many important reactions occur at the solid-liquid interface. (Stevenson, 1985).

The organic matter affects aeration, structure, drainage, moisture-holding capacity, and nutrient availability. The last represents organic matter as both a source of some nutrients and cation exchange capacity (CEC) to hold others against leaching. This fact demonstrates that the physical and chemical aspects of soil organic matter management are completely intertwined.

Organic matter helps hold water (Hollis 1977). It accounted for over 73% of the variation in water held over a range of soils. This was expanded by Krause (personal communication) to show that the sandier the soil, the more important was the organic matter in water retention.

Soil with ample organic matter allows good air and water movement. This is important for both movement in and out of the soil. Any impediment of air movement in both directions results in a shortage of oxygen for root respiration. This results in impeded root growth and eventually top growth as well.

One basic physical property of soil that does not receive much attention is soil temperature. However, it is the most important factor in determining the appropriate amount of organic matter that we might seek to maintain in our soils. Temperature affects all reactions similarly. That is, a rise in temperature by 10°C (18°F) doubles the rates of reaction. Conversely, a temperature drop of that same amount cuts the rates in half. For example, if a soil starts the growing season at 40°F and warms to 58°, the rate of organic matter decomposition doubles. In the middle of the summer it can easily increase to 76°F. That will double the decomposition rate again. The rate will remain high until fall when the soil cools again. Thus the warmer the soil, the more difficult it is to maintain a high organic matter content. Soil texture also affects this relationship with sandy soils losing organic matter faster than finer textured soils. Many of us in the South are on soils that are sandy and very warm. Thus, we cannot hope to maintain levels much above 2% organic matter. Those on the north edge of the range (e.g., in Virginia), may maintain about 3%. With altitude, such as at the fraser fir nursery in North Carolina, we might work for 4%. In the cooler and finer textured nursery soils of the PNW, levels of 5 to 8 % are not unreasonable.

Regardless of soil texture, erosion is always a worry. The maintenance of a good organic matter level in the soil will reduce the rate of erosion. Thus, it is a form of insurance.

Lack of control of traffic across nursery fields can result in increased soil bulk density, a measure of compaction. This easily results in 15%, or more, reduction in seedling production. This process can be partly reversed by proper soil organic matter maintenance. However, traffic control is still necessary. Eventually, subsoiling will also be needed. The reverse should also be noted. A significant reduction in soil organic matter results in more damaging soil compaction.

Soil bulk density is related to several other soil properties. These include porosity, aeration, internal drainage, and mechanical impedance. Collectively, these properties strongly affect both root and top growth. Nearly all nursery soil management operations result in some soil compaction. The degree of compaction varies with the type of operation and especially the care with which it is practiced. This is true both in the nursery and in the forest (Froehlich and McNabb 1984). The loss of organic matter and compaction lead to a decrease in water infiltration and water-holding capacity, a reduction of air movement into and out of the soil, and an impedance in root penetration of the soil. Above a certain compaction level, roots are no longer able to expand at all and seedling growth stagnates (Mitchell et al. 1982).

CHEMICAL PROPERTIES AND EFFECTS

Soil chemical properties that are affected by organic matter include, acidity, nutrition, and CEC relationships. To keep us humble, let's refer to Fisher (1995) again.

"Despite all our efforts, . . . our understanding of the ecological role of humus is very poor." (Fisher 1995). "A second area in which we lack sufficient understanding is the role of C in soil solution ... in soil fertility" (Fisher 1995).

We know that the soluble C can chelate metallic ions, enhance nutrient availability, and reduce the toxic effects of Al (Fox and Comerford 1992). These soluble organic compounds are probably very short-lived. Thus, to be effective they must be continuously produced. Some estimates have suggested replacement every three days during the growing season.

Fresh plant material decomposes, releasing C, H, O, N, S, P and cations such as Ca, Mg, and K. Nutrient elements are recycled by microorganisms in the soil and in the organic matter, and are often made available for plant uptake (McColl and Gressel 1995). Interactions between inorganic elements and the organic material can have important effects on nutrient availability. For example, soluble organic acids can affect P availability through chelation. Organic acids can also prevent precipitation of P by Fe and Al oxides (Fox et al. 1990).

The topic of dissolved organic matter and its importance to soil management is quite new (Hebert and Bertsch 1995). These authors have provided a review of our current understanding of this topic. This is probably the most dynamic part of organic matter management because of the rapidity with which changes occur.

Organic matter and phosphorus (P) have a complicated relationship. The organic matter contains P and its decomposition requires P. Partly humified organic matter can solubilize both Fe and Al P compounds. Thus, P dynamics during organic matter decomposition are very complex. Some P is being mineralized while other P is being immobilized continually. Usually, between 30 and 80 percent of the P in soil is associated with the organic matter.

Soil organic compounds bind metallic ions and increase the availability of some and decrease that of others (Stevenson 1982). This is especially involved in the case of iron (Fe). The Fe is often chelated in the soil by low molecular weight organic acids. This reduces the likelihood of Fe chlorosis (Stumm 1986). Iron that is free in a well aerated soil (suitable for root growth) is usually highly oxidized and thus not available for uptake by plants. There are microbes in the soil that tend to oxidize Fe and make it less available. They are a major cause of our common mid-summer Fe chlorosis. There are other microbes that tend to reduce Fe and increase its availability. There are still others that chelate the Fe. They chelate it for their own benefit. That is so they will have Fe when they need it. In some of the chelates, the Fe is in a form that the seedlings can get and that is helpful. However, in other chelates, the Fe is not available to the seedlings at all. We must remember that these microbes are working for their own benefit. The seedling is just a bystander - sometimes a winner and sometimes a loser.

The boron (B) that plants frequently use comes from the organic matter. Thus, decomposition of the organic matter is required to maintain a supply of B in the soil. This means that a dry soil can be deficient while that same soil when moist may not be deficient without any change in the total amount of B in the soil at all. Sands that are low in organic matter are prone to B deficiency. Many nursery managers are well aware of that.

The minor elements, copper, manganese, and zinc are chelated by low molecular weight organic matter, some of which is soluble (Fox 1995). It is possible that the small molecule including these elements is taken up directly by seedling roots. The important thing is that with ample organic matter, minor element availability is enhanced.

In addition to the direct effects of organic matter on seedling nutrition, there are some less direct effects as well. These involve the soil acidity and the cation exchange capacity (CEC). In nearly all nursery soils, the CEC is highly affected by the organic matter content. This is because the two principal sources of CEC are organic matter and clay. Hopefully, very few of us manage nurseries with clay soils. The CEC of organic matter is different from that associated with clays. The difference is that the clay-CEC is independent of acidity (pH) while the CEC from organic matter is highly pH-dependent. Roughly, the pH dependent CEC will about double as a sandy soil goes from pH 3.5 to pH 7.0. Obviously, we don't want our soil to be at either extreme but it does show that if our sod becomes increasing acidic, its ability to hold nutrients on the CEC is diminished. Under very acidic conditions both the CEC lowers and lots of H is produced which further induces nutrient cation displacement. At pH 5.5 we hit a happy medium of lots of things and nutrient retention is good.

The more organic matter there is in a soil, the higher is its CEC. This, in turn, buffers the soil against rapid changes in pH value. Sandy soil that is low in organic matter and thus has a low CEC is prone to experience large and rapid shifts in pH value. Seedling development is adversely affected by such shifts in acidity.

BIOLOGICAL PROPERTIES AND EFFECTS

In this section, we finally get the organic matter and the organisms together. The constituents of the organic materials that we may add to our soil are comprised of carbohydrates, amino acids and proteins, nucleic acids, lipids, lignins, and humus. These are listed in approximate order of increasing resistance to decay. There are sometimes other materials such as waxes in some materials that also decay slowly, but they usually constitute a small part of the whole.

The study of constituents of soil organic matter was established by Waksman and Tenney (1927). They showed that pine organic matter had a higher content of lignin and a lower content of protein than crops such as our cover crops. Pines have a relatively high content of fats, waxes, and resins. Consequently, they take a relatively long time to decompose. From the standpoint of nursery soil management, those are all in favor of adding sawdust, bark, etc. to our soils. Not only do those materials contain the constituents that we want, especially lignin and its derivatives, but those last in the soil relatively long times.

The loss of organic matter from soil occurs principally as a result of respiration by microbes in the process of building their own tissues. Mostly, it is C that is lost while other elements are conserved. This process is affected by temperature, aeration, water, and nutrients. These have been discussed above. The soil must also contain microbes that are capable of doing the decomposition. This is not usually a problem. Soil fumigation will temporarily reduce the numbers and diversity of such organisms (Danielson and Davey 1969). Fungi were found to be more severely impacted than bacteria.

Some microbes can convert one class of substances into another class. For example, Haider and Martin (1977) showed that a soil fungus could transform simple carbohydrates to a group of 24 different phenolic compounds. The carbohydrates used are typical of those in cellulosic materials while the phenolics would normally be thought of as being derivatives of lignin. This further complicates our understanding of how the various original organic constituents are altered during the processes of humification.

One concept that is sometimes misunderstood is known as "priming." In this case, fresh organic material is added to soil. This food source stimulates the growth of many microbes. They attack the added organic matter and break it down. Eventually, the new material is gone but the population of decomposers is still high in the soil. In order to survive, the microflora then attack the native soil organic matter. The end result of this process is that there is less total organic matter in the soil than there was before the new organic material was added to the soil. This happens most often when easily decomposable materials, such as an immature cover crop, are added to the soil (Arsiad and Giddens 1966; Broadbent 1948).

Nearly all C loss that occurs after forested land is cleared (such as is frequently the case when a new nursery is established) happens within 20 years and most of that happens in the first 5 years (Davidson and Ackerman 1993). When tilled land is abandoned, it has been estimated that it takes about a century for the soil organic matter level to reach the pre-clearing level (Van Veen and Paul 1981).

Organic residues added to soil, ranging from cover crops to wood waste (sawdust, bark, etc.)

decompose over a long period of time. However, there are very short-lived fractions that decompose over periods of hours to days. These are followed by materials that decompose over increasingly long times: days to years, years to decades, decades to centuries, and centuries to millennia (Ellert and Gregorich 1995). Thus, some organic residues remain in the sod for a very long time.

"Proportions of total C in actively cycling fractions typically range from I to 20% for mineralizable C, 1 to 5% for microbial biomass C, and 3 to 50% for..." other constituents (Ellert and Gregorich 1995).

About one-third of the added organic C will remain in the soil at the end of the first growing season. Different methods have given rise to somewhat different estimates of just how long added C remains in soil, but it is longer than most expect. Using C- 14 dating, the mean residence time in undisturbed forest soils is about 800 years while that in tilled soil is closer to 1200 years. The reason for this difference is that the more easily decomposed C is exposed by tilling and is lost while the most resistant C remains. Thus, the average age of soil C is actually increased by tilling.

Richter et al. (1995), used the ratios of C-14 to C-12 to estimate the mean residence time of organic matter in the soil. They estimated that in the South, the most passive C in the soil has a turnover time of about 2300 years while the active C turns over in about 12 years. This suggests that fresh organic matter, such as cover crop material, will decompose rapidly and make little if any long term contribution to the stable ("passive") organic material. It is material that contains significant amounts of lignin that will remain and actually increase the soil organic matter content.

Many people refer to the ratio of C to N in organic matter and try to relate it to seedling production. Several years ago, it was reported that a better indicator was the lignin to N ratio. That ratio at least ignores the mass of cellulose that figures into the C to N ratio but has only a small effect on productivity. More recently Palm (1988) has shown that the ratio of polyphenols to N ratio is an even better predictor of productivity. This is because the polyphenols reflect only the most active part of the lignin and other heterocyclic compounds.

Various materials have been added to nursery soils as sources of organic matter. They range from fresh wood wastes such as bark or sawdust to nutrient containing fresh materials such as municipal leaves and manures to true composts. Most manures (horse, cow, pig) are safe. Poultry manure has to be handled carefully because the N is present in it as uric acid and this can damage roots. Composting poultry manure with sawdust produces excellent compost that is quite safe to use (Davey 1953; 1955; Galler et al. 1978).

Composts are sufficiently stable for use ahead of the seedling crop. Also, the volume needed is about one-half that of sawdust, etc. Purchased material must be evaluated carefully. For example, mushroom compost was found to receive sufficient additives that a salt build-up in the nursery soil occurred (Davey, unpublished).

There are at least 20 low molecular weight (LMW) organic acids that are part of the soil organic matter. They all have molecular weights below 200 (Fox 1995). Oxalic, citric, and malic acids are the most common, but many others do occur. Fungi, including mycorrhizal fungi produce considerable oxalic acid. The average longevity of LMW acids is about 3 days. Thus the amount present at any given time is a balance between formation and degradation (Fox et al. 1990). Since the breakdown occurs so quickly, the formation of these LMW acids must also be rapid and constant.

A factorial experiment involving mycorrhizae, phosphorus, and organic matter added to a soil in which *Erythrina americana* was grown for six months showed that all three treatments produced significant favorable effects on seedling growth (Gardezi et al. 1995). Interestingly, the organic matter addition produced the largest effect. The seedlings associated with the main effect of the organic matter were the tallest, had greatest root volume, had a large leaf area, and the greatest above-ground weight. The only caution I would add is that the rate of organic matter addition was rather high (0, 2.5, 5.0, and 10%). Also, it was fully humified material.

In addition to the physical and chemical effects of added organic matter (either as cover crops or material transported to the soil) there have been reported biological control of various soil-borne pests such as diseases, insects, nematodes, weeds, and some small animals. Disease and nematode control have received the most attention (Davey and Papavizas 1959; 1960; 1963; Papavizas and Davey 1960; Sayre et al. 1965).

SOIL MANAGEMENT CONSIDERATIONS

It is interesting to consider the soil requirements for organic matter decomposition and seedling root growth. They are almost identical. Both require suitable levels of oxygen, water, acidity, temperature, and nutrients (especially N), and suitable microorganisms. The only real difference is in the suitable microorganisms. For organic matter decomposition we need the decomposer microbes while for seedling growth we need the mycorrhizal fungi and for N-fixing trees we need either the rhizobia for leguminous species or the frankia for actinorhizal species.

When organic residues such as cover crops are incorporated with the soil, there are about four different outcomes that are possible. There may be an immediate increase in the organic matter and nutrient contents which is followed by vigorous decomposition and leaching which leads to an actual reduction in both organic matter content and nutrient supply. This is the priming effect discussed above.

There may be an immediate increase in the organic matter and nutrient contents which is followed by a return to the preaddition condition. There may be an immediate increase in the organic matter and nutrient contents which is followed by a retention of the elevated state of both. There may be an immediate increase in the organic matter and nutrient contents which is followed by an increase in productivity and the eventual actual increase in both components. Figure1 illustrates these possible outcomes.

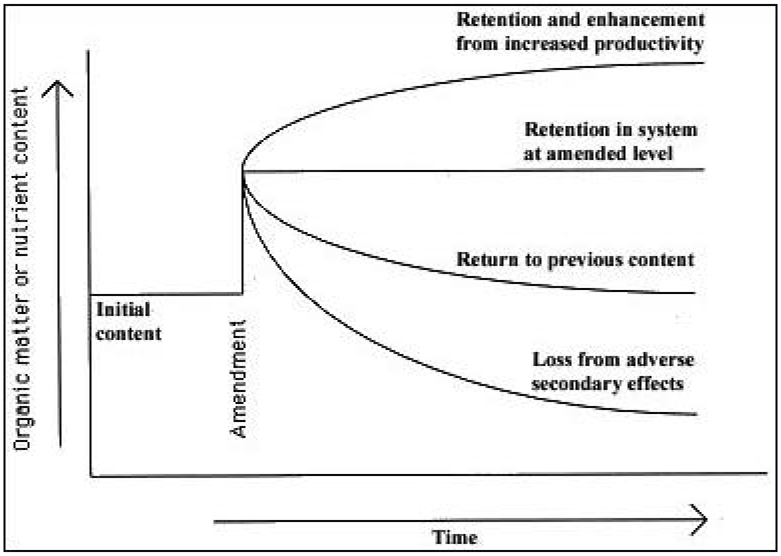

Figure 1. Potential paths of change over time following soil amendment. (Adapted from Harrison et al. 1995).

When woody materials (sawdust, bark chips, shavings, etc.) are added to soil, supplemental N is needed to avoid serious N shortage in the soil. The period of N immobilization varies with species of wood but generally runs from about 20 days for some hardwoods to 80 days for most conifers. Interestingly, the amount of extra N required is about the same (Allison et al. 1963). It is more strongly related to the amount of the material added to the soil than to the length of time required for its initial decomposition. After the time periods mentioned, the N begins to be re-mineralized and return to the soil in forms that are available to plants. Thus, it acts like a slow-release fertilizer.

Other materials added to nursery soil have included peat and municipal and industrial sludges. These are already nearly stable and require only minimal extra N. However, they also have less effect on the soil biology than sawdust, etc. Conversely, they have a very high CEC. Where available at a reasonable price, these are useful sources of organic matter. The only precaution is that they must be tested for levels of heavy metals to be sure that they are safe to use.

We must differentiate between organic matter that is incorporated with the soil and that which is used as a mulch. Sawdust is the most common material that is used for both purposes. Mulch lies on the soil surface where it has ample oxygen but limited moisture. More importantly, the decomposer microbes have very limited access to the energy in the mulch. The consequence of these factors is that the mulch decomposes very slowly and has very limited effect on the N status of the soil or seedling roots. It does slowly decompose on the soil surface but it poses little if any problem for the trees.

There are three names given to crops that we grow on nursery land between seedling crops. They are called "cover crops", "catch crops", and "green manure." Cover crops are grown to protect (cover) the soil. Catch crops are grown to catch and hold nutrients from leaching out of the soil. Green manures are grown for the purpose of producing some organic matter for the soil. In actuality, we usually want to do all three things with one crop. At the present time most people just use the name "cover crop," but we need to be aware that there actually are the three functions. In some situations, we would change the crop being grown if we wanted to stress one function over the others.

For cover crops, in the South, we tend to use grasses rather than legumes. These range from sudangrass to sudex, to sorghum to millet to milo, depending mostly on the local rainfall. In some places corn is planted. In winter, rye is the most common cover. In the coolest locations, some people use buckwheat - but it has had a history of being associated with fusarium root rots in subsequent seedling crops. When a 2-year cover rotation is used, some woodier materials can be planted, such as pigeon pea, in the first year.

Nutrients that are immediately available to seedlings or cover crops are located in the soil solution. The soil solution is considered a bottleneck through which organic matter in the solid phase must pass before it is converted to available nutrients and other soluble or gaseous constituents (Ellert and Gregorich 1995). The influence of soil management on the amount of soluble organic matter results from differences in soil climate, water fluxes, and the quantity, composition, and placement of the organic residues in the soil.

The presence of low molecular weight (LMW) organic acids strongly affects both chemical and biological processes in soil (Fox 1995). They play an important role in mineral weathering. The availability of nutrients such as P and K increases in the presence of LMW organic acids and thus improves plant nutrition (Marschner 1995). They may also complex Al and reduce Al toxicity. Conversely, the very early or incomplete decomposition of organic matter may lead to detrimental effects on seed germination and plant growth (Papavizas and Davey 1960).

PRACTICAL IMPLICATIONS

Bare root seedling production is a mining operation, as far as soil organic matter goes. Not only does frequent tilling increase organic matter oxidation and expose the soil to wind and water erosion, but lifting and shipping exports much organic matter adhering to the roots.

The organic matter content of nursery soil is usually less than in the forest. There are several possible causes for this: (1) much of the biomass produced in cultivated land is removed in the harvest and that is very true In a crop where the roots as well as the tops are harvested, (2) decomposition rates are higher in cultivated soil because of higher soil temperature during the growing season, (3) the organic substances produced by seedlings or cover crops are less resistant to decomposition than are woody residues in the forest and cultivation increases the exposure of organic materials to microbial attack by soil mixing, (4) reduced rain interception by the crop canopy increases water infiltration into the soil and results in increased leaching of soluble C, and (5) the microbial species composition may change and affect the rate of decomposition (Bouman and Leemans 1995). This last point is especially true following fumigation (Danielson and Davey 1969).

The systems in nursery soil management, organic matter maintenance, and seedling quality represent a bio-feedback system. For this to occur, the influences must work in both directions. Figure 2 illustrates these relations.

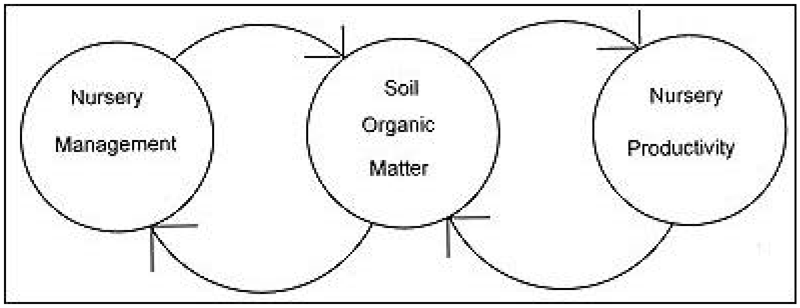

Figure 2. Linkage among forest nursery soil management, soil organic matter, and nursery productivity (Adapted from Henderson 1995).

In a study of organic matter maintenance in nursery soil, Sumner and Bouton (1981) reported that the soil organic matter level could be increased with summer cover crops. They showed that after two years, of continuous cover crops the organic matter content increased from 1. 1% to 1.4% while the fallow area decreased from 1. 1% to 0.9%. These conclusions, while valid, do not really reflect reality. The only true test would have been to complete a full rotation, including one or two seedling crops, and then determine whether the organic matter level remained elevated. I doubt that there would have been any real gain. Certainly, at the moment a cover crop is turned under, the soil organic matter level is increased by the amount incorporated with the soil. Then, however, decomposition is very rapid, as discussed above, and the increase is short-lived. The problem is that there is insufficient lignin in most cover crops to produce anything other than a very temporary boost. We must hasten to add, however, that cover crops serve several valuable purposes. Increasing soil organic matter level in a meaningful way, however, is not one of them.

In a recent study of the decomposition rates of soil organic matter particles of differing sizes, it was found that the larger particles decomposed most rapidly while the very fine particles were the slowest to decay (Hassink 1995). The reason for this reversal of expected results can be explained by the fact that the larger particles still contain some easily decomposable materials. Once those materials are gone, the resulting particle is both smaller and more resistant to decay. Finally, the smallest particles are very stable and decay only very slowly. This conclusion was valid in soils from sands to clays. It should be cautioned that in the soil, the age and particle size of the organic matter are inversely related. That is that the older the particle, the smaller it is. When we add fresh materials such as sawdust or bark, the reverse conclusion is reached. That is, that the larger particles are slower to decompose than the smaller one. That is because they are all the same material and age and the smaller particles have more surface area available for microbial attack. These conclusions are both correct and do not contradict each other.

Earlier this year, Jastrow et al. (1996) showed that C associated with small soil aggregates averages 412 years in age and for C in large aggregates it is 140 years. This agrees with the work of Hassink (1995) who showed that smaller organic matter particles are more stable and less prone to decomposition than larger particles.

Many nursery managers complain, justifiably, that obtaining organic material to apply to the soil, such as sawdust, bark, chips, shavings, etc., is both time-consuming and expensive. The expense is often due to the distance that these bulky materials must be hauled to the nursery. There is an alternative which solves most of the problems and simultaneously saves money. However, it is rarely used. The idea is to grow your own organic matter in rapidly growing coppice plantations of species such as willow, cottonwood, or paulonlia. Then harvest and chip the woody biomass during slow seasons of the year. This provides both organic matter on demand and a use for labor when other operations are not pressing. Transportation should be of very low cost since the wood is grown on or near the nursery. One nursery manager was actually cleaning up small, local woodlots of their "green junk" as a favor to the land owners. It was a win-win situation.

In addition to the various topics discussed so far, we find that soil organic matter level impacts other management practices as well. It has been established that pesticide effectivity is affected by organic matter (Upchurch 1966). Generally, the dose needs to be increased a little where organic matter is in abundance. In fact some people say that this fact is the principal reason they are interested in the organic matter level in the soil.

Organic matter serves as a source of C and energy for many beneficial soil microbes. For example, rapidly decomposing organic matter increases the soil atmosphere level of CO_2 . This, in turn, is a strong suppressant of the damping-off activity of Rhizoctonia (Davey and Papavizas 1960; Papavizas and Davey 1960).

There is a concept that ample soil organic matter and good mycorrhiza development go hand-in-hand. That is true, but it must be understood that organic matter does not usually serve as inoculum for mycorrhiza formation. However, it does enhance formation and activity of mycorrhizae. Table1 (Davey and Krause 1980) illustrates this point. It is useful to note that both soils were approximately the same texture (a fine sand).

Table 1. Influence of composted sawdust on pine seedling growth and mycorrhiza development.

Soil	Composted Sawdust (m^3/h^a)	Seedling Ht. (cm)	Seedling Wt. (mg)	Mycorrhizal Short Roots (Number/plant)
Washed river sand	0	7.9	211	0
Washed river sand	40	20.2	369	0
Sandy nursery soil	0	17.1	216	20
Sandy nursery soil	40	22.9	382	31

Finally, it is informative to understand how the level of organic matter is determined by various laboratories. Nearly all labs sieve soil samples before analysis. Consequently, the comment made earlier concerning organic matter that does not even become part of the sample is general. Beyond that, there are three distinct methods of analysis of samples, once they have been prepared for analysis. Probably the oldest method is called "loss on ignition." In this method a sample is oven-dried, weighed, placed in a furnace (±5500 C) until it loses no more weight. At that point it is assumed that all of the organic matter in the sample has burned and any weight loss can be called "organic matter." Unfortunately, the temperature required to burn all of the organic matter also begins to break down some minerals. The result is that loss on ignition nearly always over-estimates the actual amount of organic matter in soil. The other two methods were developed at about the same time. One is called "acid hydrolysis" and the second is called "alkaline hydrolysis." Acid hydrolysis is the most commonly used method. In that method a weighed sample of soil is digested in a mixture of concentrated sulfuric acid and potassium dichromate. This method detects most organic matter from the most fresh to most humified. It does not detect charred carbon. Thus, if you were interested in past fire history, this method would miss all the fine charcoal in the soil. It also underestimates the amount of organic matter in the soil. The method has a second, and serious problem. Following the test, the lab is left with a residue that is very strongly acidic and contains lots of the heavy metal, chromium. Some labs have simply been told by their State EPA to stop using the method. The alkaline hydrolysis method is much more "environmentally friendly." It Involves soaking the soil sample overnight in a weak sodium hydroxide solution. In the morning the solution is an "iced tea" color and the intensity of the color is measured against a standard to determine the amount of organic matter in the sample. The problem with this method is that the organic materials must be at least partly humified in order to be detected. Thus, this method misses both the non-humified carbon and the charred carbon. If you really want to know the amount of organic matter in the soil, the alkaline hydrolysis method underestimates it the most. The bad news is that a single soil sample analyzed by the three methods will give three distinct results. Thus, we always need to know the method used in order to interpret the results. This, of course is also true for nearly all soil test results.

SUMMARY AND CONCLUSION

Over the last half-century, emphasis on soil organic matter in forest soils has been continuous (Chandler 1995). The techniques used and the points of emphasis, such as the importance of soluble organic matter, have changed but the importance of organic matter has not (Chandler 1939; Heiberg and Chandler 1941).

How much organic matter is enough? The answer to this, as we have seen, depends mostly on climate and soil texture. Note that the native level of organic matter in soil is an equilibrium between natural additions and losses. The organic matter does not accumulate indefinitely. The situation in the nursery is the same. We add organic matter to the soil, either as cover crop or materials brought to the nursery such as sawdust or bark. The organic matter decomposes according to the temperature, moisture, and available nutrients, and we export organic matter on the roots of shipped seedlings. If the soil is managed properly, this will lead to an equilibrium, depending on location, somewhere between two and eight percent. The other side of this coin is to ask, can there be too much organic matter? That is easy to answer. NO. Plenty of work has shown that plants grow very well in 100 percent compost (Galler et al. 1978; Meyer, 1977). Also, many container mixes are nearly all organic. The reasons for that situation are quite different from the present discussion and will not be pursued further in this discussion.

Increased organic matter in soil will increase efficiency of water and fertilizer use. It will reduce the risk of disease and enhance mycorrhiza formation. Probably the largest benefit, however, will come from improved stock quality. Many nurseries these days are striving mightily to increase their proportion of grade one seedlings. Organic matter will help in this effort. The elusive short-fat seedling can be raised more easily on soil with ample organic matter than on one that is low in organic matter. Many people are lowering seedbed density (almost drastically) in order to increase seedling quality. Think about a decrease from 35 to 17 per square foot. The amount of water and fertilizer needed per seedling are each about doubled. Adequate organic matter may permit a somewhat less drastic decrease in bed density. This translates into less cost for water, fertilizer, and pesticides. This is true since these are all applied on a per acre basis - not a per seedling basis. Even lifting is less time and energy demanding if seedbed density can be maintained at a more moderate level and still produce those grade one seedlings.

The soil needs to contain both dynamic and stable organic matter. They are both important but serve different purposes. The processes of decomposition are hastened by nursery soil management. Consequently, we are always running out of organic matter and must be involved in its restoration. The modern nursery manager is in about the same situation as Sisyphus, that king of ancient Corinth who got in trouble with the Gods. We don't know what angered the Gods but we do know what the punishment was for Sisyphus. He was directed to roll a large boulder to the top of a hill. Of course at some point the boulder always slipped and rolled back to the bottom of the hill. As far as we know, Sisyphus is still struggling with that boulder. Nursery soil organic matter maintenance is a similar struggle. We can never really reach a permanent solution to the problem because the organic matter always decomposes or is shipped out of the nursery on the seedlings. Consequently, we and Sisyphus must always keep trying.

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