A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

TURFGRASS TRENDS

Section II • Volume 11, Issue 4 • **April 2002**

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MULCH

Organic Mulches Enhance Overall Plant Growth

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Nutrient cycles have been studied thoroughly in forested and agricultural ecosystems (Facelli and Pickett 1991; Wardle 1992; Attiwell and Adams 1993; Mary et al. 1996). In contrast, nutrient cycling has received little attention in ornamental landscapes, and the effects of mulch on soil fertility have been largely ignored.

Organic matter such as leaves and grass clippings are often collected and removed from ornamental landscapes, which disrupts nutrient cycles and can increase reliance on inorganic fertilizers. Mulches are used widely to suppress weeds, conserve soil moisture, direct traffic flow and enhance the beauty of landscapes (Robinson 1988). Depending on their composition, some mulches may also have substantial effects on soil fertility and plant growth.

Because these products vary widely in their C:N ratios, we predicted that they would have dramatically different effects on nitrogen availability and plant growth.

Mulches with a high carbon-to-nitrogen (C:N) ratio, such as recycled wood pallets, hardwood bark, straw and sawdust, are thought by some to induce nutrient deficiencies in plants by stimulating microbial growth, which depletes underlying soils of available nutrients.

On the other hand, mulches such as composted yard waste, or wood/bark blended with composted manure or sewage sludge may increase soil fertility and plant growth because their low C:N ratio resembles high-quality forest litter. Mulches derived from the bark of mature softwood trees, such as cypress and pine, are quite resistant to decomposition by microbes, and thus have little effect on nutrient availability. The key to understanding how different mulches affect soil-nutrient availability lies in understanding the role of soil microbes in nutrient cycling, and how they respond to addition of organic matter.

Organic matter, microbes and the cycling of nutrients

As with plants, soil microorganisms (fungi and bacteria) require energy and essential nutrients to grow and reproduce. While plants derive their energy from carbon acquired from the atmosphere through photosynthesis, the carbon in decomposing organic matter provides soil microbes with their energy supply. However, both plants and soil microbes use the same pool of essential soil nutrients. Since nitrogen is the nutrient that most often limits plant growth, the effects of mulch on soil fertility generally will be determined by how mulch affects the outcome of competition between plants and microbes for this key nutrient.

Nitrogen and other nutrients are decomposed by soil microbes (Fig. 1). The rate of

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decomposition of organic matter is affected by many factors including soil moisture, temperature and oxygen levels, but is highly dependent on the total biomass of microbes in the soil (Wardle 1992). Since microbes are generally limited by the supply of available carbon, microbial biomass can increase quickly when a biodegradable source of organic matter is applied to the soil surface.

As microbes decompose mulch on the soil surface, they acquire nutrients from the soil below in several ways. Fungal hyphae forage for nutrients in the soil much like plant roots (Frey et al. 2000). Nutrients can also be carried toward the surface in soil water by diffusion as well as evapotranspiration. Furthermore, the soil is worked continuously by earthworms, insects and natural weathering processes, which stir the nutrient pool and incorporate decomposing organic matter.

In a process known as nitrogen mineralization, inorganic forms of nitrogen (ammonium, nitrite and nitrate) are released from organic matter as it is decomposed. Once in mineral form, nitrogen can be taken up and used by plants.

Recent studies indicate that plants can also use dissolved organic nitrogen released from decaying organic matter (Nasholm et al. 1998, 2000). Plants and microbes compete for available nitrogen, and the process of nitrogen uptake by microbes is referred to as nitrogen immobilization, since any nitrogen acquired by microbes is not available to plants. Microbial turnover occurs as microbes die and decompose, releasing nutrients that can be acquired by living microbes or by plants.

C:N ratio of mulch as key determinant

The amount of nitrogen available for plants is determined by the net balance between the rate of nitrogen mineralized from decomposing organic matter and the rate of nitrogen that is immobilized by growth of soil microbes.

Microbes are considered to be stronger competitors than plants for nitrogen (Kaye and Hart 1997). In soils where nitrogen is limited, microbes generally outcompete plants for nitrogen, resulting in plant nutrient deficiencies and decreased plant growth. In fertile soils, there may be enough nitrogen to adequately support both microbial and plant growth.

The balance between nitrogen mineralization and immobilization is strongly influenced by the C:N ratio of the decaying organic matter (Facelli and Pickett 1991; Kaye and Hart 1997; Mary et al. 1996). Since soil microbes are generally carbon-limited, the addition of organic matter to the soil stimulates microbial growth. Organic matter with a high C:N ratio (greater than 30:1) does not contain enough nitrogen to support microbial growth fully. Therefore, microbes must scavenge additional nitrogen from the soil as they decompose high C:N organic matter, which decreases the amount of nitrogen available to plants.

The addition of nitrogen fertilizer to high C:N mulch (1 to 2 pounds/1,000 square feet is often recommended) can relax nitrogen competition between plants and microbes and stimulate plant growth. Conversely, decomposition of organic matter with a C:N ratio less than 30:1, which contains more nitrogen than required to support microbial growth, increases the availability of nitrogen for plants.

Our research has focused on whether this model of nutrient cycling, developed primarily through studies of forested and agricultural ecosystems, can explain effects of organic mulch on soil fertility and plant growth in ornamental landscapes. We compared two organic mulches that differ dramatically in their C:N ratios: recycled ground wood pallets with a C:N ratio greater than 100:1; and composted yard waste (a blend of wood chips, leaves and grass clippings) with a C:N ratio less than 20:1. The availability and use of both products as mulch is increasing dramatically because of recycling efforts designed to divert organic wastes from landfills (Glenn 1999; McKeever 1999).

Because these products vary widely in their C:N ratios, we predicted that they would have dramatically different effects on nitrogen availability and plant growth. Composted yard waste, with its low C:N ratio, should release nutrients at optimal rates in slow-release form, thereby increasing soil fertility and plant growth. Conversely, we predicted that the high C:N ratio of ground pallets would induce nutrient deficiencies and decrease plant growth by stimulating the growth of carbon-limited microbes resulting in high rates of nutrient immobilization.

A field study was conducted in replicated plots at The Ohio State University's Ohio Agricultural Research and Development Center in Wooster, Ohio, from 1998 to 2000. Plots were mulched with composted yard waste, ground wood pallets or were left untreated as bare soil controls. Mulch was applied to the soil surface in a layer two-inches thick. Each spring, any residual mulch was removed and replaced with fresh mulch.

Both mulches increased microbial biomass as indicated by increased microbial nitrogen and a doubling of soil respiration.

To determine how fertility might interact with mulch to affect nutrient availability, half of the replicate plots from each of the three treatments were fertilized and the other half were left unfertilized. The fertilizer used was 18:5:4 NPK, with 56 percent of the nitrogen in slow-release form (methylene urea), and 44 percent of the nitrogen in fast-release form (17 percent ammonium nitrate and 27 percent water-soluble urea). Fertilizer was applied moderately of 3 pounds/1,000 square feet/year (2 pounds to 6 pounds/1,000 square feet/year is the recommended rate for trees and shrubs), with half of the annual amount applied at budbreak in spring and half in early October.

To determine how the experimental treatments affected soil parameters, soil was periodically sampled through the growing season to a depth of 6 inches (the zone in which most fine root activity and nutrient uptake by woody plants occurs). Soil samples were then analyzed for organic matter content, microbial biomass, total extractable nitrogen, immobilized nitrogen, nitrogen mineralization rate (the rate at which inorganic nitrogen is released from decomposing organic matter), and nitrogen in forms available for plant uptake (dissolved organic nitrogen and mineral nitrogen, including ammonium, nitrate and nitrite).

The data reported represent the average of five sampling dates over the course of the 1999 growing season. A river birch (*Betula nigra* "Cully" Heritage) and rhododendron (*Rhododendron* "Pioneer Silvery Pink") were planted in each plot to determine how these soil treatments affected the growth of ornamental trees and shrubs. We also quantified flower production of rhododendron.

Mulch and nutrient cycling: research results

Mulching with composted yard waste and ground wood pallets had dramatic effects on soil organic matter, microbial activity and nitrogen cycling that were apparent after only one season. Both mulches increased the organic matter in the soil relative to the bare soil control, with the yard waste mulch having the most substantial effect.

Both mulches also increased microbial biomass, as indicated by increased microbial nitrogen and a doubling of soil respiration. These results are consistent with the hypothesis that soil microbes are carbon-limited, and that the addition of organic carbon can increase microbial biomass in the soil.

The effects that the increased organic matter and microbial activity had on nitrogen availability and plant growth, however, were highly dependent on the C:N ratio of the mulch.

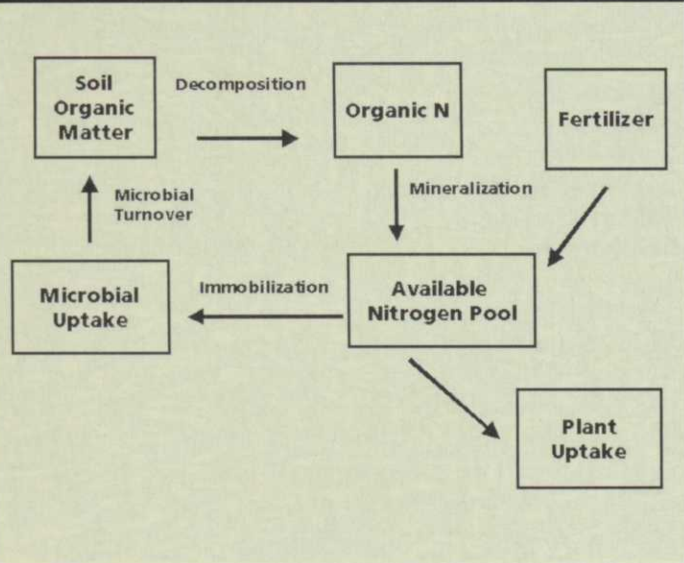
The low C:N composted yard waste mulch dramatically increased total extractable soil nitrogen, while mulching with ground wood had little effect. This is not surprising, given the high concentration of nitrogen in the yard waste mulch (about 2 percent) relative to that of the wood pallet mulch (less than .5 percent).

Most of the total soil nitrogen pool was tied up by soil microbes in all treatments, but the proportion immobilized by microbes was higher in plots mulched with wood pallets (83 percent) than in the bare soil (76 percent) or composted yard waste (72 percent) treatments. Microbial immobilization of such a high proportion of the already small pool of total nitrogen in the wood pallet plots would leave little left for plants.

In the yard-waste treatment, on the other hand, immobilization of a smaller proportion of a much larger nitrogen pool should result in much higher levels of nitrogen available for plants.

Indeed, the rate at which nitrogen was

FIGURE 1



released from decomposing organic matter (nitrogen mineralization rate) was much higher in plots mulched with composted yard waste than in the wood-pallet treatment. This greatly increased nitrogen in forms available to plants (dissolved organic nitrogen, ammonium and nitrate). Ultimately, the nutrient uptake (foliar nitrogen concentrations) were 20 percent to 25 percent higher in the composted yard waste than in the bare soil or wood pallet treatments, as well as growth of river birch and rhododendron.

Furthermore, mulching with composted yard waste increased flower production of rhododendron by more than 300 percent relative to the wood-pallet and bare-soil treatments.

Mulching with yard waste also had other substantial beneficial effects. Available phosphorus and potassium were increased, as was soil-cation exchange capacity. Furthermore, bulk density was decreased by 10 percent, which improves soil tilth and reduces compaction. Fertilization had no additional effect on the growth of plants mulched with composted yard waste, indicating that nutrients released by decomposition of the compost were able to meet fully the requirements of both microbes and plants, making additional fertilization unnecessary.

Fertilization of plants growing in bare soil increased their growth to the same level as those mulched with composted yard waste, further indicating that mulching with this compost can serve as high-quality organic fertilizer.

On the other hand, the high degree of microbial immobilization of nitrogen in the wood-pallet treatment greatly reduced the rate of nitrogen mineralization, which resulted in a much smaller pool of nitrogen in forms available for plant uptake (Fig. 4d). A similar pattern was observed for soil phosphorus levels. Not surprisingly, nutrient uptake was reduced and plants grew much slower when mulched with recycled wood pallets.

These results are consistent with the hypothesis that soil microbes are better competitors for nutrient than are plants, and that the addition of organic matter with high C:N ratios can induce nutrient deficiencies in plants by stimulating microbial growth.

Fertilization relaxed the competition between plants and microbes for nitrogen and phosphorus in the ground-wood treatment, thereby increasing plant growth. However, fertilization increased growth of rhododendron only to the level of plants growing in the untreated bare soil, indicating that fertilization compensated only partially for the nitrogen immobilizing effects of the wood pallet mulch. Fertilization of rhododendrons in the bare soil treatment resulted in plants that were 100 percent larger than fertilized plants that were mulched with ground wood pallets. However, fertilization increased the growth of river birch mulched with wood pallets to levels nearly equal to that of fertilized plants in the bare soil treatment. This indicates that river birch was better able to compete with microbes for nitrogen than was Pioneer Silvery Pink rhododendron.

Surprisingly, fertilization had little effect on soil organic matter, microbial biomass or total extractable nitrogen. Fertilization did increase soil nitrate levels, but the effect was small and short-lived relative to the dramatic effects of mulching with composed yard waste.

Increased plant growth in response to mulching has been attributed primarily to conservation of soil moisture and weed suppression. In our study, neither of the mulches had any effect on soil moisture or average soil temperature, and plots were fastidiously weeded so these variables were not a factor. Rather, the primary effects of mulches were conclusively linked to the impacts of their C:N ratio on microbial biomass and nutrient cycling as they decomposed.

Clearly, understanding the dominating influence of soil microbes on nitrogen availability is key to understanding the dynamics of soil fertility.

Horticultural implications

Mulching is one of the most used cultural practices in ornamental landscapes. Our research has shown that organic mulches can have major effects on soil fertility and plant growth. Mulching with low C:N composted yard waste increased plant growth by increasing soil organic matter, microbial biomass and nutrient availability, which demonstrates that composted yard waste serves as high-quality organic fertilizer as it decomposes.

On the other hand, high C:N mulch derived from recycled wood pallets induced nutrient deficiencies and decreased plant growth. The high carbon content of the ground wood stimulated the growth of soil microbes, which competed more successfully than plants for the limited supply of nutrients.

The nitrogen-depleting effect of mulch diminishes over time as it decomposes. As microbes die and decompose, the nitrogen they contain is released for use by plants unless the carbon source is replenished by adding fresh mulch. Nitrogen immobilization by microbes will probably have a greater impact on herbaceous plants and newly transplanted woody plants than on well-established trees and shrubs with extensive root systems.

Nevertheless, it may be best to reserve mulches with a high C:N ratio for use away from plants, such as on paths. Alternately, these products can be blended with composted materials with a low C:N ratio, such as yard waste, animal manure or sewage sludge.

Soils in landscapes surrounding new homes and other buildings are often nutrient deficient, with little organic matter because topsoil is removed and soil profiles are inverted during construction. We've shown that mulching with composted yard waste decreases compaction while increasing organic matter, microbial biomass, nutrient availability and plant growth. Yet, ironically, yard trimmings are often collected and removed from ornamental landscapes. Composting them instead for use as mulch offers great potential for rehabilitating degraded soils, while diverting a valuable natural resource from landfills.

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