

NUTRIENT MANAGEMENT IN ORGANIC APPLE ORCHARDS

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Introduction

In addition to the problems of controlling weeds and vertebrate pests in organic orchards, managing nutrients, especially nitrogen, is the other challenge to orchard floor and nutrient management facing organic growers. Just as with the use of cover crops, mulches, and cultivation, nutrient management also is an important factor affecting the quality of the orchard soil as a natural resource. Organic growers treat the soil as their most important natural resource because it is what usually distinguishes them from conventional growers, because for the most part organic growers have access to the same air, water, and sunlight as do conventional growers. It is the soil and the orchard floor above it that organic growers can use to their advantage.

Nitrogen cycle

While all nutrient cycles in the soil are important, the carbon and nitrogen cycles are the principal ones responsible for maintain soil health. Although both the carbon and nitrogen cycles are integral to each other, I will emphasize the nitrogen cycle because it is responsible for providing available forms of nitrogen to tree roots and because products from the carbon cycle are not taken up directly by roots, and so provide an indirect benefit to the trees. The air in an apple orchard, as elsewhere, is made up principally (about 80%) of gaseous N_2 , so there is abundant nitrogen around the trees but it is unavailable in this form for plant growth. Every year some nitrogen is removed from the orchard in the apple crop itself. Nitrogen that is not stored in the perennial parts of the tree (mostly bark, buds, and roots) is recycled into the orchard soil as the leaves decompose following leaf fall. Nitrogen is also returned to the soil as residues from cover crops and mulches decompose. In organic orchards, nitrogen can be added by applying compost, manure, and other high nitrogen materials, such as blood meal.

All of these forms of nitrogen are organic and cannot be taken up by the tree roots. However, through the action of a diverse soil flora and fauna, consisting of bacteria, fungi and actinomycetes, algae, earthworms, and many other organisms, organic matter is broken down into ever smaller components until it is converted into the inorganic ammonium ion (NH_4^+) by the process of mineralization. In another step, the NH_4^+ is converted into the nitrate ion (NO_3^-) by a process known as nitrification. The NO_3^- form of nitrogen is most readily available for direct uptake by plant roots. It is also the form of nitrogen with the greatest potential for leaching and contamination of groundwater. When soil pH is too high, NH_4^+ can be volatilized to ammonia (NH_3) gas and escape into the atmosphere. When soils are excessively wet, NO_3^- can be converted to N_2 gas by soil microorganisms, as they strip off the oxygen molecules to be used for respiration because of the insufficient O_2 in wet soil. Healthy soils also contain predaceous nematodes, which are predators of root knot and lesion nematodes.

Estimated losses and gains of nutrients from apple orchards

Peryea (1995) estimated the amounts of nitrogen, potassium, and calcium lost from a mature 'Delicious' orchard producing 7.7 metric tons/ha of packed fruit. Most of the nitrogen loss from these mature apple trees occurred in the leaves, which accounted for 47 kg N/ha/yr. Another 24

kg N/ha/yr was lost from the trees in the thinned flowers and fruits and tree prunings. Only 21 kg N/ha/yr was removed in the harvested fruit. Therefore, fully 77% of the nitrogen lost from the trees each year was returned to the orchard soil and becomes again available to the tree roots over time. The same situation exists for calcium, but in the case of this nutrient, over 95% of it was returned to the orchard soil. Potassium is a different, because loss was about equally divided between the leaves (53 kg K/ha/yr) and the harvest fruit (57 kg K/ha/yr). Only 15 kg K/ha/yr was lost from the trees in the thinned flowers and fruits, and an even smaller amount of potassium was lost in the tree prunings. Therefore, 44% of the potassium lost from these apple trees each year was taken permanently out the orchard in the harvest fruit.

Effects of orchard floor management on apple roots

Orchard floor management practices can affect the number of tree roots available for water and nutrient uptake. An experiment established in a 'Empire' and 'Jonagold'/MM.111 orchard planted in a heavy silty-clay loam soil in 1986 in New York State resulted in the highest numbers of apple roots after six years in plots with a 15-cm deep straw mulch around the trees (Merwin et al., 1994). A crown vetch (*Coronilla varia*) cover crop growing in the tree rows had the lowest number of roots, probably because this cover crop used nutrients and water from the soil that would have been available for apple root development. Plots cultivated deeply (8 cm) every month with a rototiller and herbicide treatment with glyphosate (Roundup) both reduced the root growth potential of these apple trees. Frequent deep cultivation probably caused physical damage to the roots. Other herbicides, such as norflurazon, diuron, and paraquat, were even more damaging to the apple roots. While mulches of biological origin probably improve the soil temperature and moisture conditions for tree root growth, synthetic mulches often result in excessive root temperatures and poor soil structure because of reduced soil aeration.

Biological nitrogen fixation

Legumes used as cover crops or incorporated into the soil as "green manure" crops are important sources of nutrients, especially nitrogen, in organic orchards. Root nodules that form on legumes absorb and fix N₂ gas into organic nitrogen compounds, which are released when the nodules decompose in the soil. Nitrogen fixation by legume pastures have supplied between 70-850 kg N/ha/yr, whereas non-legume pastures supplied 7-105 kg N/ha/yr and annual crops only 7-30 kg N/ha/yr. This explains why oversupply of nitrogen to fruit trees can occur with legume cover crops. However, through proper management practices that suppress the growth and/or decomposition of the legume cover crop (such as, mowing, flaming or burning, and using other cover crop species to compete with the legumes), the nitrogen supply to the tree roots can be limited. Biological nitrogen fixation has rarely been measured in cover crops of organic apple orchards, however, Goh and Ridgen (1997) measured nitrogen fixation rates of 33-94 kg N/ha/yr in ryegrass (*Lolium* spp.) and red clover (*Trifolium* spp.) cover crops in New Zealand.

Controlling the release and immobilization of nitrogen in the soil

The rate at which nitrogen is released or immobilized by organic matter in the soil depends on several factors, especially the carbon:nitrogen (C:N) ratio of the material. Organic materials with low C:N ratios of 15:1 to 20:1, such as legumes, will release nitrogen more rapidly, whereas materials with high C:N ratios of 40:1 to 80:1, such as grasses, may actually immobilize nitrogen during their decomposition before it is made available to the tree roots. Manure, especially if unprocessed, has very low C:N ratios, and the rapid release of nitrogen together with the salts it

contains can injury tree roots. Sawdust, which has a very high C:N ratio and is a very fine material, can immobilize nitrogen for an extended period of time, whereas coarser wood chips are not incorporated into the soil as readily and do not immobilize nitrogen as much. Other factors that affect the rate of nitrogen release or immobilization from organic matter include how well it is incorporated into the soil and the environmental conditions within the soil (that is, temperature, moisture, and aeration), which determine the metabolic activity of the soil microorganisms. Organic materials that are left on the soil surface and not incorporated into the soil will decompose and release nitrogen more slowly, but also will not immobilize it. Tree rows free of vegetation and densely shaded orchard floors will both release and immobilize less nitrogen because of the absence and reduction in vegetation biomass. A cover crop that is cut and moved into the tree row will either release or immobilize more nitrogen, depending upon its C:N ratio and the other factors mentioned, than a cover crop that is left in the alleyway. Therefore, using various organic materials and orchard floor management practices that are timed correctly for the environmental conditions in the soil, an organic grower can control the amount and rate of nitrogen that is made available to the tree roots.

Soil physical properties

Organic management of the orchard floor can improve the physical properties of the soil. A study in an apple orchard in New York State compared plots with a 15-cm thick mulch of shredded hardwood bark to plots where pre-emergent herbicides (paraquat, diuron, and norflurazon) were used (Oliveira and Merwin, 2001). For the three soil physical properties measured, the soil in plots with mulch had lower soil bulk density (g/cm^3), higher water infiltration rate (mm/sec), and higher soil porosity than the soil in the plots where pre-emergent herbicides were used, and therefore the mulched plots had better soil physical properties. A soil with a lower bulk density will have more space available for water retention and be more aerated, while a soil that has a greater water infiltration rate will take in more water and permit less water to runoff, and a soil with more porosity will permit more rapid distribution of soil water throughout the root zone. Other plots in this study that used only post-emergent Roundup herbicide had intermediate values of these properties, and therefore was less damaging to the soil's physical properties than were the pre-emergent herbicides.

Comparison of organic and conventional orchard floor management systems

In a six-year study of organic, conventional, and integrated apple production systems conducted in the Yakima Valley of Washington State, dramatic improvements in soil quality were measured in the organic and integrated production systems (Reganold et al., 2001). This study is on a commercial orchard that was planted to 'Golden Delicious'/M.9 at 2240 trees/ha in a sandy loam textured soil in 1994. Each of the four randomized, replicated blocks included plots of organic, conventional, and integrated production systems. A sodgrass cover crop was used in the alleyways of all plots and the entire area was irrigated by sprinklers. The organic system used bark mulch in the tree rows for weed control and composted poultry manure (920 kg/ha) as a nutrient source for the first two years of the study. Therefore, no additional sources of nutrients were applied to the orchard floor. Weed control methods included a mulch of synthetic woven fabric, surface cultivation, and a mowed cover crop in subsequent years. The conventional system was fertilized with calcium nitrate (186 kg/ha) in the first two years and the herbicides glyphosate (Roundup), simazine, and/or norflurazon were for weed control in all years. The integrated system received half its nitrogen from the composted poultry manure and the other

half from calcium nitrate in the first two years, with weed control by the bark mulch and Roundup only where needed. All three systems received 60 kg N/ha/yr in the first two years and a full foliar nutrient feeding program in subsequent years, with only organically certified materials used in the organic system.

Organic matter content rose quickly in the organic and integrated systems and remained greater than the conventional system throughout the six years of the study (average 1995-99: Org=3.0%, Con=2.3%, Int=2.9%). The number of earthworms was usually greatest in the organic system. The organic system also had a greater soil biomass of carbon and nitrogen (contained in the soil microbial organisms) than the conventional system (average 1998-99 per kg soil: Org=229 mg C and 82 mg N, Con=148 mg C and 61 mg N, Int=179 mg C and 72 mg N). Organic matter, earthworms, and microbial biomass are among the best indicators of biological activity within soil, and so their greater amounts in the organic system indicates that the organically managed soil had better biological properties than soil in the conventional plots. The response of the integrated system was intermediate. Soil bulk density was lowest in the organic system resulting in a soil with more space for water and air. The cation exchange capacity, which is a measure of the number of negatively charged sites on the soil particles that adsorb nutrient cations for root uptake, was also generally higher in the organic and integrated systems. While differences in total soil nitrogen were not great between the organic and conventional systems (average 1998-99 per ha: Org=2678 kg N, Con=2314 kg N), the average (1998-99) concentration of nitrate-nitrogen ($\text{NO}_3\text{-N}$), the form of nitrogen available for uptake by plant roots or leaching into the groundwater, was lower in the organic soil (5.6 ppm) than in the conventional soil (14.1 ppm). Therefore, the more active soil microorganisms in the organic system controlled the release of available nitrogen to the trees in this fertile soil. In a less fertile soil, more compost could be added or a legume cover crop could be used to hasten the release of $\text{NO}_3\text{-N}$. Soil phosphorus, potassium, and zinc were generally higher in the organic and integrated systems than in the conventional system, but dropped some in the organic system once cultivation in the tree rows began.

Despite these differences in soil biological, physical, and chemical properties, there were few and only slight differences in tissue nutrient concentrations, and every nutrient was within its recommended range. Comparing the organic with the conventional system over several years, there were: 1) no differences in leaf N; 2) only slightly higher concentrations of leaf P in the organic; 3) slightly higher leaf K concentrations in the conventional; 4) no or only slight differences in leaf Ca, Mg, and B; and 5) slightly lower leaf Zn concentrations in the organic. The organic fruit had only slightly lower N, P, and B than the conventional fruit. The lower N in the organic fruit resulted in a lower fruit N:Ca ratio, which may have contributed to our findings that the organic fruit were as firm or firmer, were sweeter, contained less acids, and stored better than the conventional fruit.

A study in New Zealand found no differences in average leaf nitrogen, phosphorus, and potassium concentrations over three years for two different cover crops (red clover and ryegrass) and a commercial compost (Bioblend applied at 5.6 kg/tree annually) in an organic 'Royal Gala' orchard (Marsh et al., 1996).

Approved organic fertilizers, plant foods, and soil amendments

In the United States, the U.S. Department of Agriculture now regulates the organic fertilizers, plant foods, and soil amendments that can be used in certified organic production. Information on these categories of materials can be found at the Internet site of the USDA's National Organic

Program (<http://www.ams.usda.gov/nop/NationalList/ListHome.html>), while a list of specific commercial products that are approved for organic use can be found at the Internet site of the Organic Materials Review Institute (http://www.omri.org/OMRI_generic_samplecrop2.html). According to the current National Organic Program regulations, approved organic materials include: elemental sulfur (also used as a fungicide); gypsum and dolomitic lime; sodium (Chilean) nitrate (limited to less than 20% of a crop's annual total nitrogen requirements); rock phosphate; potassium and magnesium sulfates; calcium chloride; soluble boron; and zinc, copper, iron and manganese sulfates, carbonates, oxides, and silicates. Materials of biological origin that can be used in organic production are: aquatic plant extracts (seaweed or kelp); liquid fish products; blood, bone, egg shell, and feather meals; humic acids; bird and bat guano; plant extracts; processed manure (heated to greater than 65°C for one hour or more and dried to 12% or less moisture content); and properly processed compost. For compost made entirely from plant materials there are no requirements, but composts that include any animal materials must be heated to 55°C throughout the pile for a minimum of three days.

Conclusions and recommendations

Based on a qualitative rating system of different orchard floor management systems (Hogue and Neilsen, 1987), mulches compare better for soil and crop quality than do herbicides. Mulches were rated as very beneficial for soil organic matter, phosphorus and potassium, and soil moisture, and for regulating tree vigor and providing good yields. Where mulches are weakest is in providing soil nitrogen, and this is where including a legume cover crop or incorporating a “green manure” crop into an organic orchard soil can be beneficial. In addition, composts, animal manures, and other organically approved materials containing nitrogen can be applied. Cultivation or tillage is generally a less desirable option in managing orchard floors because it is detrimental to soil organic matter and reduces soil moisture.

Unlike more chemically intensive conventional apple production, organic growers should understand and work with the biological processes within the orchard soil, because they have fewer and more expensive commercial options for nutrient management. Since the soil is the one natural resource that distinguishes organic from conventional farms, improving the soil is the key to successful organic farming, and orchard floor and nutrient management practices are the tools available to accomplish this goal. Specific orchard floor and nutrient management decisions depend on the unique conditions of soil and climate at the orchard site. Of course, conventional growers are free to adopt some of the same practices available to organic growers in order to benefit the quality of their soils as well. Because little research has been conducted to understand the interactions between orchard floor and nutrient management and biological processes in the soil of organic orchards, it is necessary for organic growers to test organic management practices and products themselves on small plots within their orchards. In time, as more research is conducted, we will gain a better understanding of how organic orchard floor and nutrient management practices affect the soil and then use them to improve orchard productivity and fruit quality of organic apple orchards.

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