Berry Soil and Nutrient Management – A Guide for Educators and Growers

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Dedication

This publication is dedicated to Cathy Heidenreich who was tragically killed in an automobile accident in December, 2014. Cathy put her heart and soul into her work, and this guide was the last project she had worked on before her death.

Table of Contents

Preface

Commercial berry growers in the Northeast have traditionally made standardized fertilizer applications based on crop age or past fertilization practices, and not on site specific data of plant nutrient status. This practice continues today, some 20 years or more after commercial berry crop guidelines for analysis-based fertilization programs became widely available. Adoption of soil health improving practices (including the consideration of physical and biological soil properties) has also been slow.

Research demonstrates a soil and leaf analysis-based approach to berry crop nutrition provides increased yields along with improving fruit quality and plant health. Use of soil health management practices (i.e. cover cropping, reduced tillage, compost amendments etc.) has been shown to reduce weed, nematode and soil-borne disease pressure, along with improving soil tilth, organic matter and nutrient content. Rising costs of products and concerns about environmental impacts of fertilizers make a whole farm approach to berry crop nutrient and soil management highly desirable.

Commercial berry growers who are beginning to adopt an analysis-based approach to berry crop nutrition often struggle with issues such as which test(s) to use, when to use them, how to interpret the test results received, and what types of related management practices will improve their soil and nutrient management.

Moreover, Ag educators are frequently called on to cover multiple commodities and/or information areas outside their field of expertise, and also struggle to assist commercial berry growers with berry crop soil and nutrient problems.

This manual has been designed as comprehensive resource, a "one-stop-shop", for commercial berry growers interested in improving berry crop soil and nutrient management and the Ag educators advising them.

Chapter 1: Introduction to Soil Management in Berry Production – *Dr. Harold van Es, Cornell University*

What is soil?

The Soil Science Society of America defines soil as, "the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants." For commercial berry growers, soil is the growth medium that supports production of their crops. The types of soils available, their physical, chemical, and biological characteristics, their past, present, and future management all contribute to their suitability and sustainability for berry crop production. (Page 9 photo*: planting beds ready for plastic-laying, photo courtesy H. van Es*)

Site selection is ***critical*** to successful berry crop management; if a grower starts out with an inherently low quality soil it is often extremely difficult if not impossible to overcome soil constraints that limit yield and productivity of the berry

Why do I need to manage soil health and when?

The most opportune time for soil health improvement is prior to planting. Thus it is neither efficient nor expedient to randomly select a site and establish berry plants without first assessing the suitability of the soil for berry crop production. Careful consideration of the available soils and their characteristics should be made in light of berry crop requirements. Once a suitable site with an appropriate soil is selected, additional soil management practices may be called for to further improve soil health prior to planting.

For example, subsoil properties are not regularly assessed, but are important for perennial crops such as berries. Soil health improvements that may need to be implemented prior to planting might include such things as drain tile installation, subsoil fertility amendment, pH correction, deep ripping to break up compaction or fragipan layers, cover cropping for the same and/or to increase soil organic matter content, reduce soil pathogens, compost addition to boost organic matter content and/or increase soil biological activity. Slope and aspect are important considerations for site selection for high value, long-lived perennials; slope for water runoff and air drainage and aspect for best growth. Nearness and/or availability of irrigation are also important.

Soil health management does not end once the plants are in the ground. Post-establishment soil and nutrient management is also critical to successful berry crop production: periodic soil testing in conjunction with foliar analysis to monitor plant nutrient status, continuing pH monitoring and/or adjustment, addition of amendments such as fertilizers and/or compost side dressings to maintain fertility, establishment of row middle cover crops, etc.

What are the benefits of soil health management?

Soil health management can provide multiple short-term and long term benefits for commercial berry growers:

- Maximizes yield potential in terms of quantity and quality of fruit produced
- Improves and maintains plant health
- Extends the life of the planting
- Reduces inputs and corresponding management costs
- Facilitates sound environmental stewardship

Soil health concepts

Soil health is the capacity of the soil to function. The function in the case of berry crops is sustaining plant health and facilitating good yields.

All soils are not created equal

Overall quality of a particular soil is a result of both its inherent and dynamic qualities. *Inherent soil quality* results from natural soil forming processes and long-term geologic, biotic, climatic and topographic factors.

Physical characteristics contributing to inherent soil quality include soil type, soil texture (sand/silt/clay content), stoniness, internal drainage (may be modified), soil depth, presence of barriers such as fragipan, clay layer or tillage pan (may sometimes be modified), and slope.

Chemical characteristics that play a role in inherent soil quality are pH, P, K, Ca, Mg, Fe, Al, Mn, Zn, B and Na content (these may be modified by use/management practices) and salt accumulation (this varies by location across the US.)

Finally, a biological characteristic contributing to inherent soil quality is organic matter content; organic matter serves as part of the nutrient exchange complex, increases the moisture holding capacity of the soil, provides compounds that help maintain soil structure and supports biological activity (organic matter content may be modified over the long-term).

Liebig's Law of the Minimum states yield is proportional to the amount of the most limiting nutrient, whichever nutrient that may be. We now know this law should be applied in a broader context where the limiting factor may be soil chemistry and/or a physical or biological factor.

Information on inherent soil quality may be obtained from soil survey reports and includes things such as basic soil properties and suitability for use. Information on inherent soil quality may also be obtained from on-line tools such as Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/). More information on how to use this tool is provided in Appendix A.

Dynamic soil quality results from changes due to human use (management) either in a positive or negative sense. Evaluation of dynamic soil quality, as portrayed by a Cornell soil health test, provides more detailed information than inherent soil quality characteristics alone. The Cornell soil health test consists of standard soil nutrient analysis enhanced with 4 biological and 4 physical indicators. The test uses chemical analysis results in conjunction with these indicators to identify soil constraints, allowing growers to initiate management actions to overcome them prior to planting.

The most important part of the whole puzzle in terms of soil testing and soil fertility for any berry crop is getting soil pH to the right level for optimum crop performance ***before planting***, and ***keeping it there.***

Characteristics of healthy soils

What are the characteristics of a healthy soil? Sufficient soil depth for plant root development is important; a soil depth of 8 inches or greater is preferred in the case of berry crops. A healthy soil should have good tilth, water storage and drainage. It should have sufficient *but not excessive* nutrients and be free of chemicals harmful to plants such as heavy metals, herbicide residues or other contaminants.

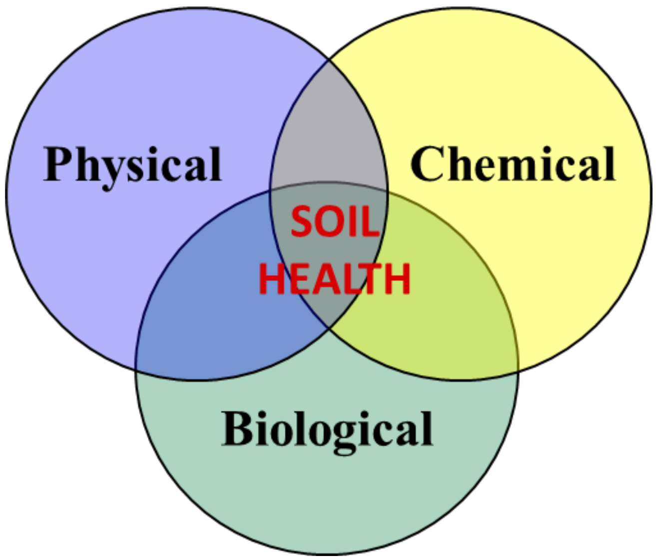
Healthy soils should have low populations of plant disease and parasitic organisms such as fungi, bacteria, nematodes, springtails, and so on. Conversely, a healthy soil should contain high populations of beneficial organisms like mycorrhizae and earthworms.

Finally, healthy soils should exhibit resistance to being degraded and along with that – resiliency or the ability to recover quickly from adverse events such as flooding, drought, hurricanes, etc.

Understanding the three soil health processes

Think of soil health then in terms of the three major realms that impact it: the physical, the chemical, and the biological. These three realms intercept and interact (Figure 1); thus it is important to view each of these more as processes than characteristics. If any process is compromised, the others are also affected. A healthy soil is balanced in this respect and therefore provides for better growing conditions, crop resiliency and reduced inputs.

- **Support**
- **Aeration, water infiltration**
- **Resistance to soil erosion**
- **Physical root proliferation**
- **Organism movement**



- **Nutrient storage and release**
- **Soil reactions**
- **Energy (carbon) storage**

- **Pest suppression**
- **Nitrogen mineralization**
- **Organic matter decomposition**
- **Support of microbial community**

Figure 1: *Soil health – an expression of the interactions between chemical, physical and biological processes in soil*

Over past decades, chemical aspects of soil were, in general, perhaps overemphasized; not to a fault necessarily, as good testing procedures and crop recommendations were the outcome of these investigations. But at the same time, not nearly as much attention was paid to the physical and biological aspects of soil. Research is ongoing in the physical and biological realms today, providing a more complete snapshot of soil health and as a result, more comprehensive short-term and long-term management strategies for soil health improvement.

The chemical processes

The chemical processes in soil provide essential nutrients for plants. pH is a ***critical*** component of the chemical process as it affects nutrient availability. Any changes in pH must be addressed, before the planting is established; failure to adjust pH to optimal levels for the crop will seriously impact plant establishment as well as future crop production. pH adjustment is more difficult after a perennial crop is established and may reduce the success of the planting.

The chemical process also includes both macronutrients (nutrients needed in larger quantities (such as N, P and K) secondary nutrients like Ca, Mg and S and micronutrients required in smaller quantities (such as B and Zn); specific recommendations have been developed for correcting deficiencies of these nutrients essential for berry crop production.

The physical processes

The physical processes of soil may be limited by inherent or dynamic qualities; some of these may be remediated; others may not.

Poor internal drainage is often due to local hydrology and impeding soil layers (fragipans) resulting in poor aeration which reduces root growth and function and may support disease development. Poor internal drainage may also be a result of past management practices such as compaction, intensive tillage, etc. Poor internal drainage is frequently identifiable from a soil survey; however, on-site excavations are recommended to evaluate the extent of the condition. Internal drainage issues may be remediated through installation of subsurface drain lines and use of raised beds to reduce susceptibility to imperfect drainage (aerobic vs. anaerobic conditions).

Poor water availability is mostly a function of soil texture, organic matter content and rooting depth. Compaction reduces root proliferation and water access by plants. Often this condition may be improved through deep ripping and/or compost additions. Where coarse soils with good drainage are present in humid climates mild water stress readily occurs; in dry years drip irrigation is almost always required.

Soil aggregates (crumbs) come in various sizes (0.002 to 2 mm in diameter) and are composed of soil particles (sand, silt and clay) held together by moist clay, organic matter, organic compounds produced by bacteria and fungi, and fungal hyphae (threads).

Well aggregated soils consist of about 50% soil aggregates and 50% soil pores. These soils typically have a range of pore sizes; the pores are important for drainage, aeration, and rooting**.** Small pores are important to long-term moisture retention. Intermediate pores are needed for water retention and biological function. Large pores occur between medium size aggregates and facilitate drainage; they are most often lost with compaction.

Good soil structure is important to plant growth and development. Roots need soil pores > 0.2 mm in diameter or larger to move through soil and strength <300 psi to penetrate, porous loose fitting crumbs and blocks as is found with a well –aggregated (naturally softer) soil.

Compacted soil structure is characterized by a surface crust, tightly packed crumbs, large blocks with few cracks, and subsoil compaction. Compacted soils are subject to extended periods of saturation, standing water; compacted plow layers (big clods), are more disease prone, limit rooting; and experience problems with infiltration and erosion.

Plow layer compaction may have one or more causes including loss of organic matter (and thereby aggregate stability) from intensive tillage, lack of organic matter additions, traffic on wet soil, lack of controlled traffic, and/or soil settling from heavy rain.

Subsoil compaction, unlike plow layer compaction, evidenced by big clods, is very invisible and more difficult to address. Causes of subsoil compaction include heavy traffic on wet soils (i.e. manure spreaders), use of equipment with poor weight distribution (with more modern equipment there is less of this problem), and a long history of plowing, especially wheel in open furrow plowing.

Identifying compaction layers - Penetrometers, shovels, and trenches for root observations are good diagnostic methods to identify and locate compaction layers .Measuring penetration resistance with a simple tool called a penetrometer is one way to begin to locate and assess compaction layers. Penetrometers are relatively inexpensive, around $200. Often, extension offices or soil and water conservation offices have penetrometers growers may borrow to use for this purpose.

Mediating compaction layers – Mitigation of deep (subsoil) compaction requires deep tillage, and/or deep-rooted cover crops. For shallow compaction layers a different strategy is in order.

The biological processes

Understanding soil biology is very much at forefront of our science today. Soil represents a complex environment with highly variable conditions. Most biological activity occurs near the surface of the soil where most of the organic matter is located. There are 3 general types of organic matter found in soil: Living, dead, and very dead. All 3 play important roles in helping produce high yields of healthy crops. Adding organic matter to soil results in many benefits (see Chapter 9 for more detail).

Living organic matter is comprised of those soil organisms that play important roles in making nutrients available, suppressing disease, producing plant growth promoting hormones, creating humus, aggregating soils. These might include such things as bacteria, fungi, nematodes, earthworms, mites, springtails, collembolans, moles, and many other types of organisms. These organisms often interact in very, very complex ways. They use resources in soil in various ways, decomposing organic matter, cycling nutrients, influencing plants and other biota, and responding to their chemical and physical environment: i.e. in compacted soil we find less numbers of soil organisms along with less diversity of organisms present.

How Do Management Practices Affect Soil Life?

- **Intensive tillage** reduces mycorrhizal colonization and diversity of soil organisms
- **Organic matter application** increases diversity, density & activity of fast growing microorganisms
- **Fertilizer application** proliferates the growth of fast growing microorganisms and reduces nitrogen fixation, and mycorrhizal colonization
- **Irrigation/drainage** benefits either anaerobic or aerobic soil organisms depending on whether either is adequate or inadequate.

Examples of Soil Process Interactions

(chemical, physical, biological)

- **Hard soil** reduces **rooting**
- **Compacted soil** suppresses **beneficial biological processes**
- **Compaction** increases **root diseases** and **denitrification losses**
- **Organic matter decomposition** increases **aggregation**
- **Prolific rooting** decreases **compaction**
- **Poor drainage** reduces **rooting** and **aerobic biological processes**
- **High sodium content** reduces **aggregate stability, drainage, aeration,** and **rooting**
- **Tillage** increases **bacteria** and decreases **fungi**

Soil organisms may also manipulate the chemical and physical environment of the soil in a beneficial way. Examples of these soil organisms include plant roots, organic matter decomposers and mycorrhizae.

Mycorrhizae are non-pathogenic fungi that live in a symbiotic relationship with roots of higher plants, enhancing nutrient uptake by the plant (P, N, K, micronutrients), especially P. They also assist in soil aggregation, provide a form of defense against pathogens, protect plants against metal phytotoxicity, and enhance plant fitness (pollen quality, plant-pollinator interaction). They are especially beneficial in undisturbed soils.

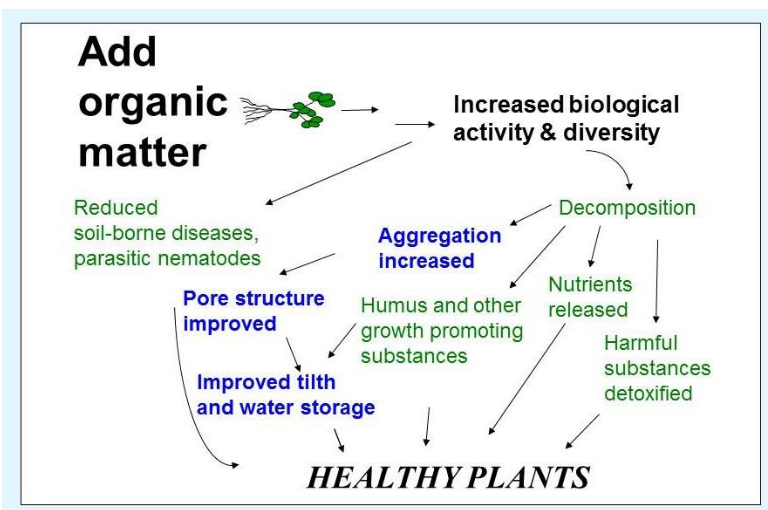
Suppressive soils are described as those that for various reasons suppress soil-borne pathogens such as *Pythium*, *Phytophthora*, *Rhizoctonia*, etc. This may be due to the presence of organisms with suppressive ability: (direct suppression or out-competing through larger population numbers) including *Pseudomonas aureofaciens*, *Bacillus subtilis*, *Trichoderma*, *Paxillus involutus*, etc.

Another living component of soil is plant roots- the below ground portion of plants, which are typically very beneficial to the soil.

Dead organic matter is composed of recently dead soil organisms and crop residues that provide food (energy and nutrients) for soil organisms to live and function. Dead organic matter is also called “active” or “particulate” organic matter. This is the other essential partner in mineralizing nutrients for plants, aggregating soils, and forming humus.

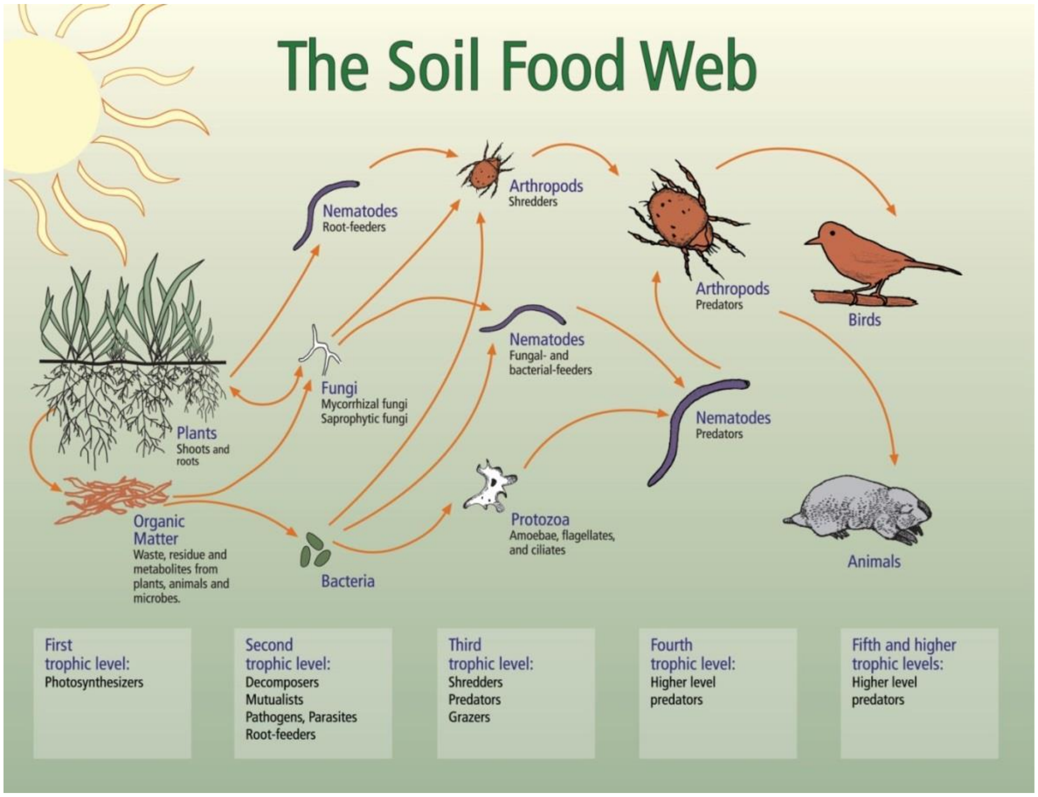
Very dead organic matter is not a biologically active fraction; rather it consists of well-decomposed organic materials, also called humus. Humus supports the chemical activities of soil; it contains very high amounts of negative charges that hold nutrients and cations in the soil. Humus also has high water-holding capacity, and stores carbon.

Adding organic matter results in many benefits.



Feeding the soil vs. feeding the plants – a different paradigm

Natural soil ecosystems evolved with little disturbance as forest or grassland. Nutrients were recycled through organic materials such as leaves and animal droppings. Decomposing materials “fed the soil” nutrients and carbon and stimulated diverse biological activity. This mineralized (inorganic) nutrients and then “fed the plants” (plants only take up basic mineral nutrients)



A Soil Food Web Glossary

Arthropods	Invertebrate animals with jointed legs. They include insects, crustaceans, sowbugs, arachnids (spiders), and others.
Bacteria	Microscopic, single-celled organisms that are mostly non-photosynthetic. They include the photosynthetic cyanobacteria (formerly called blue-green algae) and actinomycetes (filamentous bacteria that give healthy soil its characteristic smell).
Fungi	Multi-celled, non-photosynthetic organisms that are neither plants nor animals. Fungal cells form long chains called hyphae and may form fruiting bodies such as mold or mushrooms to disperse spores. Some fungi, such as yeast, are single-celled. **Saprophytic fungi:** Fungi that decompose dead organic matter. **Mycorrhizal fungi:** Fungi that form associations with plant roots. These fungi get energy from the plant and help supply nutrients to the plant.
Grazers	Organisms, such as protozoa, nematodes, and microarthropods, that feed on bacteria and fungi.
Microbes	An imprecise term referring to any microscopic organism. Generally, "microbes" includes bacteria, fungi, and sometimes protozoa.
Mutualists	Two organisms living in an association that is beneficial to both, such as the association of roots with mycorrhizal fungi or with nitrogen-fixing bacteria.
Nematodes	Tiny, usually microscopic, unsegmented worms. Most live free in the soil. Some are parasites of animals or plants.
Protozoa	Tiny, single-celled animals, including amoebas, ciliates, and flagellates.
Trophic levels	Levels of the food chain. The first trophic level includes photosynthesizers that get energy from the sun. Organisms that eat photosynthesizers make up the second trophic level. Third trophic level organisms eat those in the second level, and so on. It is a simplified way of thinking about the food web. In reality, some organisms eat members of several trophic levels.

Figure 2. *Soil food web – a bottom up effect where the abundance of a resource affects the abundance of its consumers. Source: Soil Biology Primer http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/ [August 7, 2013].*

In modern agriculture, with the onset of the use of fertilizer and soil disturbance through tillage – we have accelerated organic matter mineralization. Use of chemical fertilizer had led to feeding plant directly with mineral nutrients; with this practice we have essentially stopped feeding soil organisms.

Summary

For perennial crops such as berries, the most opportune time for soil health improvement is prior to planting.

Additional Resources

1. *Magdoff, F. and van Es, H. 2009. "How good are your soils?" Chapter 22 in Building Soils for Better Crops: Sustainable Soil Management, 3rd edition. Sustainable Agriculture Research and Education (SARE) program handbook series no. 10. 294 pp.* http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition
2. *Soil Biology Primer* http://soils.usda.gov/sqi/concepts/soil_biology/biology.html
3. *Cornell Soil Health Manual* http://soilhealth.cals.cornell.edu/extension/manual.htm
4. *Soil Quality for Environmental Health web site* http://www.soilquality.org/home.html
5. *Soil Quality/Soil Health – USDA NRCS web site* http://soils.usda.gov/sqi/
6. *Managing Cover Crops Profitably, 3rd edition* http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition
7. *Cornell Cover Crops Decision Tool* http://covercrops.cals.cornell.edu/decision-tool.php
8. *Midwest Cover Crop Council Cover Crop Decision Tool* http://mcccdev.anr.msu.edu/

Chapter 2: Soil Testing for Berries– *Ms. Janet Fallon, DairyOne*

What does a soil test measure?

A soil test is a process using chemical analyses to assess current nutrient levels in soil. Elements (phosphorus, potassium, calcium, magnesium, sodium, sulfur, manganese, iron, copper, aluminum and zinc) are chemically removed from the soil and measured for their "plant available" content within the sample. A soil test also measures soil pH, humic matter and exchangeable acidity. These analyses indicate whether lime or sulfur are needed to change the pH, and, if so, how much to apply. Components of soil testing include field sampling, extraction and chemical analysis, interpreting analytical results and making a fertilizer recommendation based on those results.

Why do I need to soil test and when?

As indicated in chapter 1, soil health management does not end once the plants are in the ground. Post-establishment soil and nutrient management is also important to successful berry crop production.

This includes periodic soil testing (every three years or so) in conjunction with foliar analysis to monitor plant nutrient status, pH monitoring and/or adjustment as needed to maintain nutrient availability for good plant nutrition, and addition of amendments such as fertilizers and/or compost side dressings to maintain fertility.

What are the benefits of soil testing? Think of soil testing as a crop management tool to be used both preplant and post-plant to optimize crop yield and quality. Much like the hand lens you may use to scout for diseases and insect pests, a soil test can provide an early warning that potential problems may be looming on the horizon. It also provides advisement on how to address potential issues once they have been identified, such as soil pH modification and required fertilizer inputs. In the same fashion, soil test results may indicate all is well and no action is needed at this time. Thus costly over or under fertilization may be avoided maximizing profitability. In addition to avoiding costly over fertilization, soil testing may also be considered as an environmental protection tool, preventing introduction of excessive nutrients into the ecosystem.

A word about soil pH

Figure 4 shows the relationship between soil pH and nutrient availability in soil. Most nutrients are highly available around the middle of the pH range (7.0). Iron is an exception, becoming more available with lower pH. Most berries prefer a well-drained sandy loam at a pH of 6 .2 to 6.8, and an organic matter content of >3%. A good alfalfa soil would be suitable for strawberries or raspberries. Blueberries on the other hand prefer a loamy sand with an organic matter content of >4% and low P; they perform best at a pH between 4.2 and 4.8. Blueberries and cranberries typically thrive in poorer low cation exchange capacity (CEC) soils (<18). Iron deficiency in blueberries is often an indication pH is too high in the planting.

Poor sample = crummy results!

Soil and nutrient testing is often last on the priority list for berry growers and as a result sampling may done in a haphazard fashion if and when time permits, often by someone drafted for the task that is not familiar with it. How you take a soil sample determines the accuracy and repeatability of the soil test. It also determines lime and fertilizer requirements for the planting which, in turn, plays a role in optimizing yield and fruit quality. Avoid costly over and under fertilization errors by taking the time to collect clean, representative soil samples.

Routine vs. diagnostic soil testing

Use routine soil analysis to get lime and fertilizer recommendations for establishment or maintenance of a berry planting where no known history of fertilizer problems exists.

Diagnostic analysis is suggested when a nutrient imbalance is the suspected cause of poor crop performance and/or foliar symptoms. Collect paired samples from “good” and “bad’ areas of the field to confirm a problem. Consider adding a soluble salts test to the standard soil test package in this case. Use plant tissue analysis in conjunction with a diagnostic soil analysis to further assist in the diagnosis.

Collecting soil samples

Establishing a sampling schedule

Many Ag educators frequently receive panicked “after-the-fact” soil and nutrient management questions in cases where growers planted first and asked questions later. To best utilize this crop management tool it is important to establish a routine sampling schedule for berry crops, starting before planting establishment.

Soil testing should be done preplant; at minimum one year prior to blueberries and 6 months prior to other berries. This is critical because growers need to allow adequate time for added lime or sulfur to react with soil when remediating pH levels. Once berry crops are established, testing should be repeated every 2-3 years or as needed for troubleshooting. Post-establishment soil testing is often conducted in conjunction with plant tissue testing to determine what’s in the soil as compared to what’s getting into the plant. Periodic soil testing is also useful to determine fertilizer needs for permanent row middle cover crops.

Pick a time for routine soil sampling (spring or fall) and stick with it, rather than testing at various times during the year. Fall is the most reliable time of year to consider for several reasons:

- Soil pH determination is more reliable when soil is moist
- Seasonal fluctuation of soil pH occurs when soils dry out in mid-summer causing an increase in salt concentrations. This allows Ca^{++}, Mg^{++}, and K^{+} to replace H^{+} and Al^{+++} on the soil surface. The extra H^{+} and Al^{+++} in the soil solution will temporarily decrease soil pH hence pH determination is more reliable in fall when soil moisture is a bit higher.
- Fall sampling allows time to apply needed lime and fertilizer before spring establishment.
- Fall sampling and subsequent application allows time for lime or sulfur to react with soil.
- Leaf sampling for tissue analysis is typically done at the same time in late summer/early fall.

Using the right sampling tools

What tools of the trade are needed for soil sampling? It depends in large part on soil conditions and soil types that need to be sampled.

Use stainless steel probes for best results in sampling. This prevents iron contamination from rusting tools such as non-stainless steel shovels and/or trowels. For the same reason plastic pails are preferable to galvanized for holding and mixing subsamples to prevent zinc contamination.

A stainless steel soil probe is faster to use than an auger in soils with fewer stones or gravel; it is also easier on your back. A slit sided probe with a foot peg is a good place to start. A lubricant such as WD 40, PAM, Dove dish soap, or silicone may be used to prevent plugging of probe unless a micronutrient deficiency (Fe, Zn, Mn, or Cu) is suspected. A probe works best in dry soils with few rocks; in wet soil conditions a probe pushes wet soil down and rocks plug it up. Soil probe prices range from $50 to $1,000 for standard soil test probes or kits; more for automated sampling devices.

Sources for Soil Probes and Augers

- **Oakfield Apparatus** www.soilsamplers.com
- **Gemplers** http://www.gemplers.com
- **Graingers** http://www.grainger.com
- **Ben Meadows** http://www.benmeadows.com
- **Amazon** http://www.amazon.com

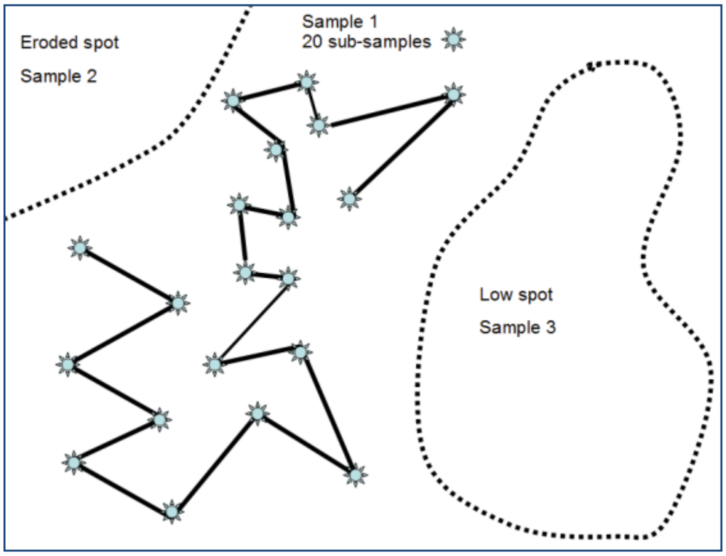
Augers work best for rocky or wet soils, or when sampling eroded knolls. Wet soils tend to stick to auger flights as they do soil probes but samples are better able to be collected using an auger. A plastic container (i.e. a pint freezer box) with a hole drilled in the middle collects soil as auger pulls it out of the ground. A power drill may be attached to the auger which speeds up the process if a lot of samples are being collected.

Shovels or spades, providing they are of stainless steel in construction, are OK for occasional use in soil sampling. However, when using these implements, you will need to “trim” edges as the wedge –shaped samples they collect are not representative. This makes it slower and tougher to get a good sample using these tools verses a probe or auger. When large numbers of samples are required, an automatic sampler should be considered. These are gaining in popularity with precision agriculture; they are most consistent in untilled sites and for deep sampling. Hand probes are best for the shallow sampling needed in berry plantings.

Sampling techniques

How do I decide what my sampling area should be? Sample each management area separately, especially problem areas with a suspected nutrient imbalance. For precision agriculture it is recommended that growers take one sample per acre; realistically smaller growers take one sample for each 4-5 acres.

How do I decide where to take my subsamples? Identify the sampling area or management area to be tested. Then take subsamples in a zigzag pattern in each management area. Grid sampling can be a good tool but can be very expensive and time consuming when done properly. "Directed" sampling based on topography may be more meaningful on smaller acreages. Here are some rules:



- Avoid unusual areas such as dead furrows, farm lanes, old hedge rows or fence lines, old manure, lime or burn piles, wet or severely eroded areas.
- Take separate samples from areas within the field that vary widely in color, slope, soil texture, drainage, productivity or crop history.
- Avoid sampling immediately adjacent to drip tape.

How many subsamples should be taken? "The more the better" to get an accurate and representative sample for the management area. In general, collect 8 to 10 subsamples on area of <2 acres; collect 10 to 20 subsamples on an area > 2 acres (between 2-3 subsamples per acre).

How deep should I sample? The rooting depth for most berry crops falls within the surface 0 to 8" of soil. It is also important to note that Cornell berry crop recommendations are based on this 0-8" sampling depth. So whether you are collecting samples for a preplant recommendation or established stand, be sure to sample to an 8" depth. Once you have the preplant recommendations, also be sure to plow down suggested amounts of lime, sulfur and/or nutrients to the same depth then disc. *(Left: proper soil sampling depth for berry crops. Photo source Ohiowine and more http://www.ohiowineandmore.com/)*

Taking the subsamples and preparing the final sample(s) for submission. Avoid sampling under extremely wet soil conditions. Samples usually leak in transit; moreover some nutrients undergo rapid biological transformations in very wet soils. Be sure to discard the organic "matt" (1-2") on top of the subsample along with any soil in the subsample below the 8" depth when collecting subsamples. Mix subsamples completely in clean plastic pail or bag; if subsamples are muddy, air dry before mixing. Remove large stones and break up large clods before mixing sample thoroughly. Air dry samples in a thin layer on a clean (plastic not metal) surface; fan assisted drying is acceptable, but heat assisted drying is not.

Complete **all** of the required information on the sample box before filling and make sure it matches the information on the sample information sheet; fill out the sample information sheet **completely.** Keep a copy for your own records.

Place about ¾ to 1 pint (roughly 2 cups or less) of the mixed sample in the box or bag provided by the lab and close it securely. Avoid using commercial bag or boxes; the glue for these has been found to contain Boron and may alter test results especially if sample is wet.

If using the Dairy One lab (http://www.dairyone.com/) for soil testing, fill out Form F for Commercial Fruit. You must provide a valid soil name to get a fertilizer recommendation. If you do not know the soil name for the management area you are testing, you may find it from a variety of sources listed below, including Web Soil Survey, an on line mapping tool. Instructions for using this tool are provided in Appendix A.

There are places on the form to include previous cropping history, and designate the future crop (preplant). Write legibly.

Types of Soil Tests

- **Bray 1** – acid/neutral soils of North Central USA
- **Mehlich 3** – works well on a broad range of soils
- **Olsen** (bicarbonate test) – used in alkaline soils of the western US
- **Morgan** – developed for acid soils in the northeast; uses sodium acetate.
- **Modified Morgan*** – Morgan with improved micronutrient extraction using ammonium acetate.

*Agro-One standard test

Ship the sample to: DairyOne, 730 Warren Road, Ithaca, NY 14850. Free pickup, shipping and handling may be available; visit the web site for details: www.dairyone.com. **Other soil testing services exist throughout the Northeast (see page 22).**

Soil test options

Comparing one lab to another is not a good idea in terms of uniformity and consistency of test results; different labs use different extraction procedures giving different numerical results and subsequent recommendations. Soil test options include: Olsen, Bray 1, Mehlich 3, Morgan, and Modified Morgan. Each type of test measures a different amount of P and K depending on the extractant chemical used for the test. Fertilizer recommendations are then based on field rate and response studies calibrated against the P and K determined by the soil test.

Resources for Determining Soil Names

- **Official Soil Series Descriptions (OSD)** http://soild.usda.gov/technical/classification/osd/index.html
- **Web Soil Survey** (mapping tool) http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm
- **iPhone app** http://itunes.apple.com/us/app/soil-web-for-the iphone/id354911787?mt=8
- **County soil map** your local CCE office
- **SoilWeb app for iPhones and Droid phones** http://casoilresource.lawr.ucdavis.edu/drupal/node/902
  This application retrieves graphical summaries of soil types associated with the phone's current geographic location. Sketches of soil profiles are linked to their official soil series description.

Sufficiency "values" (ppm or lb/A) are specific to the extractant used; thus they vary between test types. Test results provide an index of availability and crop response. In general, those falling in the low to very low range, if remediated, are likely to see a crop response with nutrient addition. Those falling in the optimal range are likely to see a marginal crop response; those in the high to very high range are unlikely to see a crop response.

Cornell Nutrient Analysis Lab ranges for Dairy-One soil tests are slightly more delineated. Nutrients in the very low range (below optimum) indicate the nutrient level or pH is sufficiently low to require extra inputs of lime or fertilizers. Low range (below optimum) indicates the nutrient level or pH is below normal and higher than normal fertilizer rates are required for maximum economic yields. Medium (optimum) range suggests the nutrient level or pH is sufficient for normal fertilizer and lime rates to produce maximum economic yields. High range (above optimum) indicates the nutrient level or pH is adequate for economic yields. And finally, excess (above optimum) indicates the nutrient level or pH is too high and may either cause plant injury or interfere with the availability or uptake of other nutrients. For some nutrients an excess will also increase the probability that the nutrient will contribute to pollution.

Boron testing

Most soil tests do not routinely include boron. A hot water soluble boron test is offered in addition to the standard soil testing for a small additional fee through either the Dairy-One lab or in conjunction with the Cornell soil health test (more on this test in chapter 8). Boron testing is highly recommended for berries and other crops as it plays a role in root development and elongation and is often deficient in northeastern soils.

Boron uptake is sensitive to pH, especially in blueberries; if pH is too high, boron may not be taken up by plants. In this instance, test results will indicate sufficient levels of boron present in soil while leaf test results indicate a deficiency; pH adjustment usually results in improved boron levels in leaves without additional boron amendment. Boron will be discussed in more detail in subsequent chapters.

University-related Analytical Labs

- **Agro-One Agronomic Laboratory** **http://dairyone.com/analytical-services/agronomy-services/about-agro-one/** **and Cornell University Nutrient Analysis Laboratory** **http://cnal.cals.cornell.edu/**
- **University of Delaware Soil Testing Program** **http://ag.udel.edu/dstp/**
- Michigan State University Soil and Plant Nutrient Laboratory http://www.spnl.msu.edu/
- Penn State Agricultural Analytical Services Lab http://agsci.psu.edu/aasl
- Rutgers Soil Testing Laboratory http://njaes.rutgers.edu/soiltestinglab/
- University of Connecticut Soil Nutrient Analysis Laboratory. http://www.soiltest.uconn.edu/
- **University of Maine Analytical Laboratory and Sol Testing Service** **http://anlab.umesci.maine.edu/**
- University of Maryland
- UMass Amherst Soil and Plant Tissue Testing Laboratory http://soiltest.umass.edu/
- University of New Hampshire Soil Testing http://extension.unh.edu/Problem-Diagnosis-and-Testing-Services/Soil-Testing
- University of Vermont Agricultural and Environmental Testing Lab http://pss.uvm.edu/ag_testing/
- Rhode Island
- West Virginia University Soil Testing Laboratory http://soiltesting.wvu.edu/

Commercial Analytical Labs

- Spectrum Analytic (Ohio) http://www.spectrumanalytic.com/
- Logan Labs (Ohio) http://www.loganlabs.com/

How do I select which lab to use?

Select a lab that offers procedures and guidelines that are appropriate for your region and your soils. Do not use test results from one lab or procedure and sufficiency ranges from another lab or procedure.

Also use caution in comparing one lab to another even when they use the same extractant; there will be some lab-to-lab variability for the same procedure including: weigh vs. volume (in terms of test sample size), use of ICP phosphorus (P) tests vs. colorimetric P tests, soil to solution ratios used, shaking time for samples in extractants, types of grinders used to process samples.

Summary

The most important part of the whole puzzle in terms of soil testing and soil fertility for any berry crop is getting soil pH to the right level for optimum crop performance before planting, and keeping it there. Soil testing is required for optimum yield and quality of berries; sample technique is key- garbage in, garbage out!

Soil sampling checklist:

- *Establish a sampling schedule*
- *Use the right sample tools*
- *Sample at the correct depth*
- *Take enough subsamples*
- *Air dry, mix & ship to lab in box/bag provided from lab*
- *Select the appropriate service*
    - *Routine or diagnostic*
    - *Morgan/Modified Morgan/Mehlich 3*
- *Use the correct sufficiency ranges for the lab and services selected*
- *Follow up every 2 to 3 years with subsequent soil testing and tissue analysis*

Additional Resources

1. *Magdoff, F. and van Es, H. 2009. "How good are your soils?" Chapter 22 in Building Soils for Better Crops: Sustainable Soil Management, 3rd edition. Sustainable Agriculture Research and Education (SARE) program handbook series no. 10. 294 pp.*
2. *Pritts, M. 2012. Site and Soil Requirements for Berry Crops:* *http://www.fruit.cornell.edu/berry/production/pdfs/sitesoireqsmfru.rev.pdf*

Chapter 3: Understanding Your Berry Soil Test Results – *Dr. Marvin Pritts, Cornell University*

Let's review

The goal of soil testing is to estimate the plant-available nutrient levels in soil. Soil tests do not tell you how much of a particular nutrient is in soil, they estimate how much of a particular nutrient in soil is available to the plant. So the extractant mimics what a plant root might have available to it; they don't do this perfectly so a variety of extractants have been developed, each with their own unique advantages and disadvantages (i.e. *Bray, Olsen, Mehlich III, Morgan, Modified Morgan, Sodium bicarbonate)*; no extractant is perfect.

Soil test recommendations

Ensuing test results are accompanied by recommended levels of amendments to bring up levels to some optimum (*Figure 2a*). Recommendations from different labs have different philosophies. Some want to build up the soil nutrient bank so there is never any risk of nutrient being limited (#1). Others want to apply just enough to where the economic gain from the additional amendment is equal to the cost of the added amendment (#2).

Figure 2a. *Plant response curve*

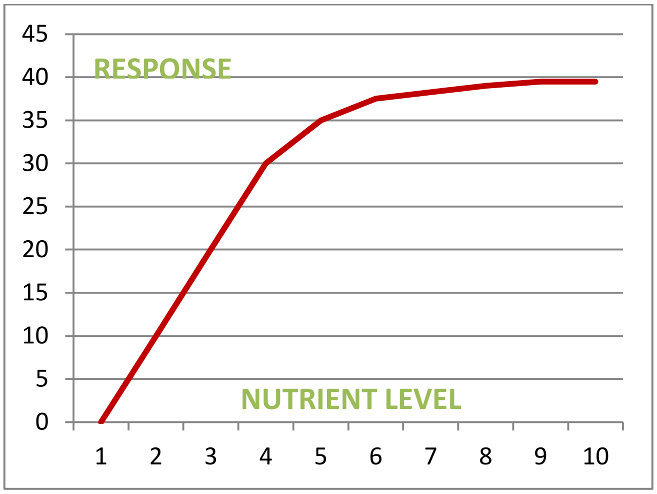
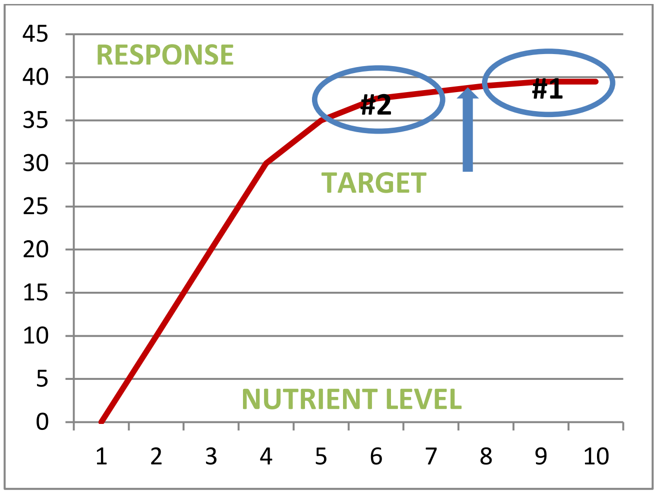


Figure 2b. *Recommendation philosophies*



For berries and other perennials crops the ideal is somewhere between #1 and #2 because of the difficulty of incorporating nutrients annually (*Figure 2b*). So it's best to add P, K, Ca, and Mg prior to planting as they need to be incorporated for best effect.

So, except for sandy soils, the eventual nutrient supply (soil repository plus fertilizer) should be mostly sufficient for the life expectancy of the planting- without annual supplementation (apart from nitrogen). Nitrogen is rapidly lost from soil through use by plants and microorganisms, and leaching; it moves easily into the rooting zone with annual applications. Conversely, it is difficult to move nutrients like phosphorous and potassium into the root zone when perennial plants are already established. That makes it important to build up a little bit of a bank for long lived crops like raspberries and particularly blueberries.

When soil tests are done and recommendations come out, every soil is probably going to give you a slightly different response curve to the crop of interest. You can't develop response curves for every soil type in any given state, so some generalizations have to be made. The truth of the matter is these response curves have not been developed for strawberries, raspberries, and blueberries on all different soil types. Oftentimes agronomists have generated these curves for field crops, but not so much for berry crops, so educated guesses need to be made on how berry crops will respond. One approach is to find an agronomic crop that has a similar response to a berry crop and use that as a guide; for example, strawberries/raspberries mimic alfalfa so alfalfa guidelines can be used as a basis for a recommendation as these three crops have the same rooting depth, pH requirements, and are all perennial.

Researchers have generated nutrient response curves for some berry crops, but there just aren't many available to use for calibration. Below is an example of a response curve for nitrogen in strawberries (*Figure 3*). Fertilizer was applied in a liquid form so it's not easily converted to pounds per acre, but the point is at low N levels, not much response occurs, and while more response is seen as N increases, the rate of increase diminishes. Leaf area increases with increasing N (277% between 10N and 20N); but yield is not nearly as responsive to increasing N (increasing only 22% when N is doubled); the optimal rate is about 10 N or equivalent to about 100 lbs/A year.

Figure 3. *Response of strawberries to increasing amounts of nitrogen fertilizer.*

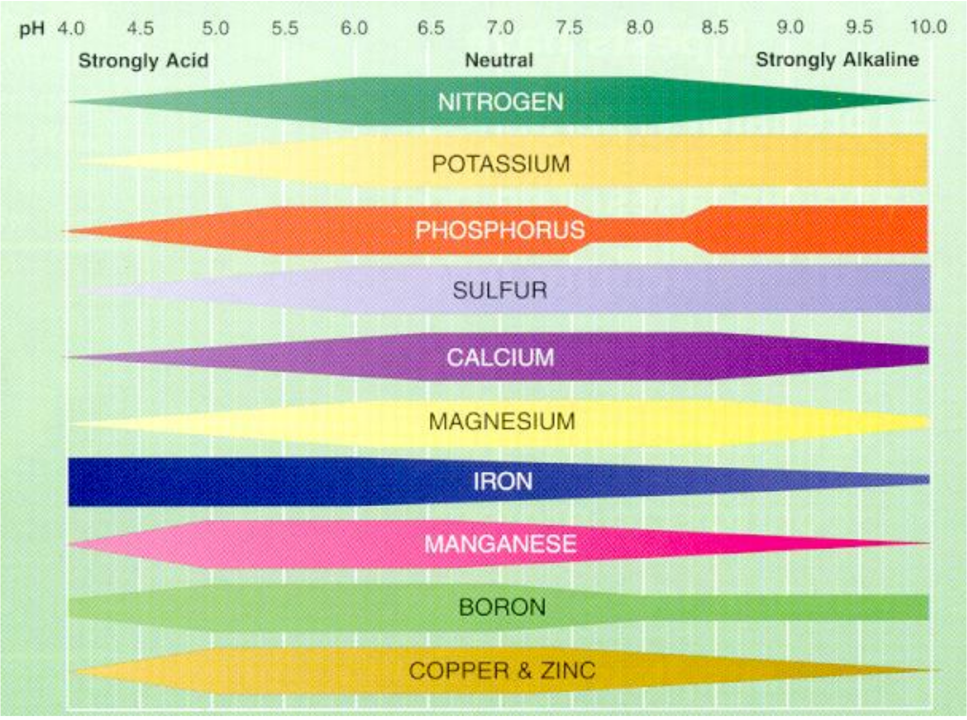
	0 N	**5 N**	**10 N**	**15 N**	**20 N**
Leaf Area(cm^2)	627.2	1725.2	2493.9	3003.7	3903.4
Crown (g)	13.4	29.4	39.8	44.6	45.6
Runner (g)	4.1	6.5	22.0	31.1	39.1
Roots (g)	7.6	20.4	31.3	41.4	59.0
Yield (g)	97.0	166. 9	172.7	214.7	210.8

Optimal Rate

Some recommendations are based on response curves that are dependent on soil type (e.g. Morgan extractant). Others are less dependent on soil type (modified Morgan) mostly due to the differences in the amount of potassium extracted. You have to assume test results are good and accurate and that the recommendations are on target. Recommendations should be mostly the same whether one is organic or conventional; the difference lies in the sources of the fertilizer/amendment used – not in the recommended amount of nutrient needed. So, for example, the recommendation might be for 50 lb potassium regardless of growing method. The source of that potassium applied for the organic vs the conventional grower may differ, however. There are a few exceptions to this depending on release rate; some organic amendments have slower release rates so higher amounts may be indicated.

The most important adjustment we usually make is to soil pH. If pH is not within a desired range, then the ability of the plant to take up nutrients will be compromised (*Figure 4*). If pH is not right you can apply a lot of a particular nutrient to soil but it will not be available to the plant because of the pH. The amount of nutrient available to the plant is very dependent on soil pH. (*Right: iron deficiency in blueberry, photo courtesy M. Pritts)* The optimal soil pH range for most crops is 6.0 to 6.5; at this range most of the nutrients are readily available. The exception to this rule is blueberries where the optimum is down around 4.5.

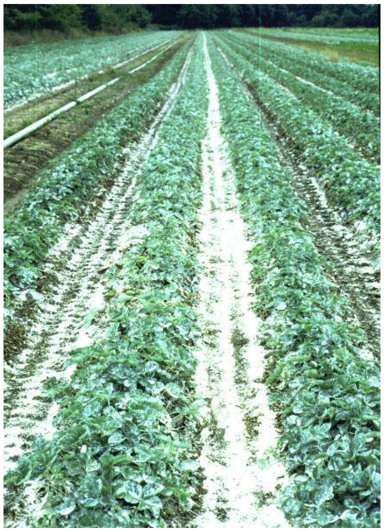
Figure 4. *Availability of soil nutrients in relation to pH.*



Adjusting soil pH

Changing the pH after planting is very slow and difficult. Sulfur or lime to adjust pH is best applied preplant in order to work it down into soil adequately (*Figures 5a and 5b*).

Figures 5a and 5b. *Post plant application of lime to strawberries (left) and raspberries (right). Photos courtesy M. Pritts. NOTE: This is not a recommended practice.*



Sulfur can be used to lower pH and lime can be used to raise pH. Aluminum sulfate is often recommended in catalogs for lowering pH. Aluminum sulfate does provide a rapid change of pH, but excess aluminum is toxic to plants, so it is not the best choice.

The amount of lime to apply is dependent on: 1) The difference between current pH and target pH (how big is the gap between where you want to be and where you are) and 2) cation exchange capacity (CEC) or soil buffering capacity. CEC is the ability of the soil to hold onto cations in the soil through exchange sites (negative charges on soil particles), and it is the ratio of the cations to these exchange sites that determine pH (cation/hydrogen ion ratio). This ratio is often called "base saturation" or the percent of the exchange sites occupied by bases. Bases include Ca++. Mg++ and K+ these are the most important. Exchange sites not occupied by cations are populated by Hydrogen ions (H+). The higher the ratio of hydrogen ions to cations, the more acid the soil is. The greater the number of hydrogen ions you need to knock off the exchange sites, the more base (Ca and Mg) will be needed to do so.

Exchange sites are comprised of negatively-charged clay particles and organic matter that hold onto the positively charged cations. Soils that are high in CEC require more sulfur or lime to change the pH, but once adjusted, are more stable. The reverse is also true, soils low in CEC are easier to adjust but revert back to low pH as the Ca and Mg ions leach from soil and are replaced with hydrogen ions, dropping the pH again. To reiterate: It's easy to raise pH of sandy soil with low OM (low CEC). It is hard to lower pH of clayey soil having higher OM content as clay and OM contribute to negative charges in soil.

Table 1. *Amount of sulfur (lb/A) required to lower pH to a desired level of 4.5 for blueberries.*

Current pH	Sand	Loam	Clay
5.0	175	530	5800
5.5	350	1000	1600
6.0	660	1880	3030
6.5	1250	3560	5730

The amount of sulfur to lower pH to a desired level of 4.5 depends on the current pH and the soil type (*Table 1*). The further from target pH of 4.5, the more sulfur is needed to lower pH, and the higher the CEC capacity of soil, the more sulfur is needed to lower pH. It extremely difficult to lower pH for alkaline (high pH) soils with a high CEC as extremely large amounts of sulfur are required. The initial sulfur expense, coupled with the need for additional sulfur on a biannual basis to reach/maintain lower pH makes this prohibitive. For this reason these soils are often deemed unsuitable for blueberry production.

Soil tests attempt to estimate the amount of lime (or sulfur) required to bring the pH to within the desired range for a particular crop based on cation exchange capacity, CEC (*Table 2*). Soil tests do not measure CEC directly; they do not measure the number of negative charges present, or the number of these populated by hydrogen ions. They use indirect methods to estimate the amount of hydrogen ions on the exchange complex. One would suppose lime recommendations would be extremely precise, but most often they are an estimate, putting you within the ballpark. The reasons for this are 3-fold: estimating CEC is an inexact science, different procedures are used among labs, and CEC varies with pH and other factors.

Table 2. *Cation exchange capacity (CEC) of various soils.*

Material	CEC (cation exchange capacity)
Sands	2 – 10
Loams	7 – 25
Clays	20 – 40
Humus (organic matter)	200 - 400

Adding lime or sulfur to the soil does not change the pH instantly. Significant time is required for lime or sulfur to affect pH (6 months or longer). The rate of pH change is affected by the particle size of the lime or sulfur (smaller, quicker, larger slower), soil moisture (dry soils, slower, moist soils, faster), temperature (slower in winter, faster in spring, summer, fall), and good aeration as oxygen is needed for the biological process of pH change to happen.

Interpreting soil test results

Results (and reports) vary from lab to lab. Below is a sample strawberry soil test report from the Agro-One lab in Ithaca, NY, which will be used to highlight things to note when reviewing soil test results and recommendations.

Checklist: Things to look for when interpreting soil test results for berry crops

- ✓ **Soil pH**. The desired pH for strawberries 6.0 to 6.8 (this sample is in that range…). Check the fertilizer recommendations at the bottom of the report; in this instance, no lime or sulfur is suggested as the pH is acceptable at 6.1. Note buffer pH is also listed. Buffer pH is used to estimate CEC; greater the difference between pH and buffer pH, the greater the CEC capacity, and the more difficult to modify the pH.

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low	Low	Medium	High	Very High
Phosphorus (P)	4	8	9	*****************				
Potassium (K)	88	176	175	**************************				
Calcium (Ca)	1,802	3,605		*******************************				
Magnesium (Mg)	302	603		*******************************				

Water		Calcium Chloride		No Till		Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
pH	Buffer pH	pH	Buffer pH	pH	Buffer pH					
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre

Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations	tons / acre	lbs / acre			lbs / 1000 sqft			
Year Crop	Lime	N	P2O5	K2O	Lime	N	P2O5	K2O
1 Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

- ✓ **Organic matter content** - 2% or higher most desirable for berry crops; OM. If OM is 2%or less, cover crops or compost applications should be implemented to boost OM prior to planting.

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low	Low	Medium	High	Very High
Phosphorus (P)	4	8	9	***************				
Potassium (K)	88	176	175	************************				
Calcium (Ca)	1,802	3,605		****************************				
Magnesium (Mg)	302	603		****************************				

Water pH	Water Buffer pH	Calcium Chloride pH	Calcium Chloride Buffer pH	No Till pH	No Till Buffer pH	Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre

Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations

Year	Crop	Lime (tons / acre)	N (lbs / acre)	P2O5 (lbs / acre)	K2O (lbs / acre)	Lime (lbs / 1000 sqft)	N (lbs / 1000 sqft)	P2O5 (lbs / 1000 sqft)	K2O (lbs / 1000 sqft)
1	Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

- ✓ **Macronutrient levels** (P, K, Ca, and Mg). These are generally reported in either parts per million (PPM) or pounds per acre (lb/A). PPM x 2 equals pounds per acre so it is easy to convert between the two values. The columns to the right of lbs/acre indicate the relative levels of soil nutrients, which vary by soil type and crop being grown. “High” is considered a sufficient level and may not generate a fertilizer recommendation. “Medium” is considered adequate for the short term but may generate a recommendation to maintain and/or build levels for the future, as in the case of phosphorus in the report below. (Other macronutrient components displayed in Appendix C).

- ✓ **Soil fertilizer recommendations**: Note the recommendation of 25 pounds per acre refers to pounds of actual nutrient, not pounds of fertilizer. For example, an N-P-K fertilizer such as 10-10-10 is only 10% P_2O_5 by weight, so to apply 25 lb P you would need 25/0.1 or 250 lbs of fertilizer. Note at the same time you would also be applying 25 lb/ac of N and K. To avoid over applying potassium which you already have in sufficient supply consider using a fertilizer like Monoammonium phosphate (MAP) 11-52-0 which is 11% N, 52% P_2O_5 and no K. (Further fertilizer recommendations in Appendix C).

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low, Low, Medium, High, Very High
Phosphorus (P)	4	8	9	**************
Potassium (K)	88	176	175	***********************
Calcium (Ca)	1,802	3,605		**************************
Magnesium (Mg)	302	603		**************************

Water pH	Water Buffer pH	Calcium Chloride pH	Calcium Chloride Buffer pH	No Till pH	No Till Buffer pH	Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre

Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations

Year	Crop	Lime (tons / acre)	N (lbs / acre)	P_2O_5 (lbs / acre)	K_2O (lbs / acre)	Lime (lbs / 1000 sqft)	N (lbs / 1000 sqft)	P_2O_5 (lbs / 1000 sqft)	K_2O (lbs / 1000 sqft)
1	Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

✓ **Nitrogen**: Nitrogen is not usually reported in soil test results as the amount in soil at any given time changes rapidly due to cycling between the various forms of N (NO_3, NO_2, NH_4, and organic N), weather changes, and leaching. Thus, the nitrogen recommendation in this report is based on annual strawberry crop requirements for N rather than soil test results. Use foliar nitrogen test results to adjust this rate accordingly (see Appendix C).

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low, Low, Medium, High, Very High
Phosphorus (P)	4	8	9	**************
Potassium (K)	88	176	175	***********************
Calcium (Ca)	1,802	3,605		**************************
Magnesium (Mg)	302	603		**************************

Water pH	Water Buffer pH	Calcium Chloride pH	Calcium Chloride Buffer pH	No Till pH	No Till Buffer pH	Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre

Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations

Year	Crop	Lime (tons / acre)	N (lbs / acre)	P_2O_5 (lbs / acre)	K_2O (lbs / acre)	Lime (lbs / 1000 sqft)	N (lbs / 1000 sqft)	P_2O_5 (lbs / 1000 sqft)	K_2O (lbs / 1000 sqft)
1	Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

- ✓ **Micronutrient levels** (ICP analysis): Aluminum, zinc, manganese, and iron values are reported here; these levels are not generally used for recommendations as foliar analysis a better indicator of the status of these micronutrients. Thus it is good to review both soil and leaf analysis results together. When test results indicate micronutrients are present in soil but foliar tests indicate deficiencies, it may indicate either pH is not in the desired range, or other root issues exist that are affecting micronutrient uptake. That said these values may require some consideration in evaluating possible toxicities. One example of this is aluminum; soil aluminum levels above 300 PPM are considered toxic to blueberries. The same levels are not necessarily toxic to strawberries and raspberries, as the higher the pH the less available aluminum becomes in soil (Appendix D).

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low / Low / Medium / High / Very High
Phosphorus (P)	4	8	9	***************
Potassium (K)	88	176	175	************************
Calcium (Ca)	1,802	3,605		*****************************
Magnesium (Mg)	302	603		*****************************

Water		Calcium Chloride		No Till		Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
pH	Buffer pH	pH	Buffer pH	pH	Buffer pH					
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre								
Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations

		tons / acre	lbs / acre			lbs / 1000 sqft			
Year	Crop	Lime	N	P2O5	K2O	Lime	N	P2O5	K2O
1	Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

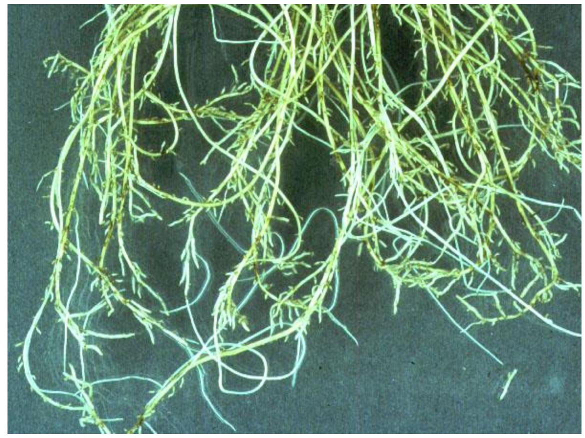
Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

Note that boron is not reported on this test. Boron may also have impact on plant growth; particularly in strawberries and raspberries; in this case it is more likely to be a deficiency rather than an excess as with aluminum. Request boron testing if it is not included in the standard soil test you are using. Recommended boron levels may vary slightly from lab to lab but in general boron levels of < 0.35 PPM (multiply by 2 for lb/A) are considered low for berry crops; soils with 0.35 to 0.75 PPM are considered medium and soils with > 0.75 PPM are considered high.

Soil boron is very prone to leaching, especially in soils with low organic matter content, so it is one of the most commonly observed micronutrient deficiencies in berry plantings. Boron deficiencies lead to poor root growth (*Figure 6*), which in turn causes deficiencies of other nutrients due to poor uptake. This sometimes manifests itself when leaf analyses indicate micronutrient deficiencies, even though the soil pH is in range and soil test results indicate sufficient levels of the nutrient(s). Note that poor root growth from other causes may have the same effect. Boron is also important in fruit set. Boron is highly mobile in soil and may be applied any time of year, making a boron deficiency fairly easy to correct. If boron is required apply no more than 2 lb actual boron/A (i.e. 10lb/A Solubor) in any one year.

Figure 6. *Comparison of strawberry roots grown in complete nutrient solution including boron (left) and nutrient solution minus boron (right). Note sparse, stubby roots of boron deficient plant. Photos courtesy: M. Pritts.*



- ✓ **Comments**: This section contains nutrient recommendations as well as information on application methods, timing and other relevant information.

Component	Mod. Morgan ppm	Mod. Morgan lbs/acre	Morgan Equiv. lbs/acre	Soil Test Levels: Very Low	Low	Medium	High	Very High
Phosphorus (P)	4	8	9	*******	*******	*		
Potassium (K)	88	176	175	*******	*******	*******	***	
Calcium (Ca)	1,802	3,605		*******	*******	*******	*******	
Magnesium (Mg)	302	603		*******	*******	*******	*******	

Water pH	Water Buffer pH	Calcium Chloride pH	Calcium Chloride Buffer pH	No Till pH	No Till Buffer pH	Organic Matter (%)	Nitrate-N (ppm)	HWS Boron (lbs/acre)	Soluble Salts (mmhos/cm)	Total N (%)
6.1	5.9					4.6		0.9		

Other Nutrients, Mod. Morgan, lbs/acre

Sodium (Na)	Aluminum (Al)	Sulfur (S)	Zinc (Zn)	Manganese (Mn)	Iron (Fe)	Copper (Cu)	Boron (B)	Molybdenum (Mo)
	62.6		0.5	14.6	5.6			

Soil Fertilizer Recommendations

Year	Crop	Lime (tons / acre)	N (lbs / acre)	P2O5 (lbs / acre)	K2O (lbs / acre)	Lime (lbs / 1000 sqft)	N (lbs / 1000 sqft)	P2O5 (lbs / 1000 sqft)	K2O (lbs / 1000 sqft)
1	Strawberries, Spring	0.0	100	25	0	0.0	2.3	0.6	0.0

Comments

Nutrient recommendations provided by Cornell University.
These are general comments. Always consult with your crop advisor for recommendations specific to your farm.
For assistance interpreting your report, contact your local Cooperative Extension office at 607-272-2292.
Yr1 Apply 80 lbs/acre of N in July, and another 20 lbs/acre the first of September. Do not apply N in early spring except on sandy soils.
Yr1 Apply fertilizer uniformly around the plants or through drip irrigation. Do not allow granules to remain on leaves. Do not fertilize when leaves are wet.
Yr1 The best time to apply potassium and phosphorus fertilizers is in the fall before mulch is applied.
Yr1 Use both a soil test and leaf analysis to adjust nutrient levels.

You must have confidence in recommendations provided by your lab. The best analysis in the world is useless without a good recommendation; many analytical labs provide "general plant recommendations for field crops" without fine-tuning to the needs of specific crops i.e. a blueberry recommendation that looks like one for corn.

Appendix B provides conversion factors for determining fertilizer application rates for fields smaller than one acre for various berry crops. **Appendices C through E** provide nutrient concentrations for various fertilizers.

Test Your Skills – Interpreting Berry Soil Test Results

What follows are seven examples of soil test results, summarized in tabular form for ease of reading. Test your skills by reviewing the soil test results checklist for each report, then make a recommendation based on your observations. Answers/recommendations follow in the box at the bottom of each page.

Exercise 1: Strawberries, Clay Loam Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	High
Calcium (Ca)	High
Magnesium (Mg)	Low
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	1.5
Zinc (Zn)	
pH	5.2
Organic Matter	5.3%

Your checklist:

- ✓ **pH**:______________________________
- ✓ **Organic Matter**:______________________________
- ✓ **Macronutrients (P, K, Ca, Mg)**:______________________________
  ____
- ✓ **Micronutrients:**______________________________
  ____

Your Recommendation(s):______________________________

____

____

____

Checklist: pH should be 6.0 to 6.5 for strawberries. Phosphorus is a little low; also magnesium low;
Recommendation: Lime to raise pH; apply high magnesium (dolomitic) lime to correct both pH and Mg in one step, plus phosphorus.

Exercise 2: Blueberries, Sandy Loam Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	High
Potassium (K)	High
Calcium (Ca)	Low
Magnesium (Mg)	High
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	1.5
Zinc (Zn)	
pH	4.8
Organic Matter	5.3%

Your checklist:

- ✓ **pH**:______________________________
- ✓ **Organic Matter**:______________________________
- ✓ **Macronutrients (P, K, Ca, Mg)**:______________________________
  ____
- ✓ **Micronutrients:**______________________________
  ____

Your Recommendation(s):______________________________

____

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____

Answer: pH ok; others OK, Calcium is low – what to do as the pH ok? **Recommendation:** Gypsum or Calcium sulfate to increase calcium; these forms do not affect pH.

Exercise 3: Raspberries, Loamy Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	High (15)
Potassium (K)	High (140)
Calcium (Ca)	High (4,367)
Magnesium (Mg)	High (409)
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	
Zinc (Zn)	
pH	6.2
Organic Matter	5.3%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ **Macronutrients (P, K, Ca, Mg)**:____
  ____
- ✓ **Micronutrients:**____
  ____

Your Recommendation(s):____

____

____

____

Answer: Levels seem ok – would soil test recommend anything here? Recommendation: High levels of one cation (Ca) can suppress uptake of the other two…Ca /Mg ratio higher than 100; typical ratio in soil is 5.
Recommendation: Apply magnesium sulfate to add small amount of Mg to soil to balance ratio.

Exercise 4: Blueberries, Sandy Loam Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Low
Potassium (K)	High
Calcium (Ca)	Medium
Magnesium (Mg)	Medium
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	2.0
Zinc (Zn)	
pH	5.9
Organic Matter	1.3%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ **Macronutrients (P, K, Ca, Mg)**:____________________________________
  ____
- ✓ **Micronutrients:**____
  ____

Your Recommendation(s):____

____

____

____

Checklist: pH 5.9 out of range for blueberries (4.2 to 4.5); organic matter low (< 2.0); P and K low; Mg slightly low. **Recommendation:** Lower pH, increase organic matter; other values may fall in line once this is done so no other recommendations apart from that at the moment.

Exercise 5: Blueberries, Clay Loam Soil, (preplant)

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	High
Calcium (Ca)	High
Magnesium (Mg)	High
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	2.0
Zinc (Zn)	
pH	5.9
Organic Matter	4.3%

Your checklist:

- ✓ **pH:**____
- ✓ **Organic Matter:**____________________________________
- ✓ **Macronutrients (P, K, Ca, Mg):**______________________________
  ____
- ✓ **Micronutrients:**____________________________________
  ____

Your Recommendation(s):____________________________________

____

____

____

Checklist: CEC high, pH and OM high, already high in Ca, Mg. **Recommendation:** Don't Grow Blueberries! This is not a suitable blueberry soil; select another site.

Exercise 6: Strawberries, Sandy Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	High
Calcium (Ca)	Low
Magnesium (Mg)	Medium
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	0.5
Zinc (Zn)	
pH	5.6
Organic Matter	1.1%

Your checklist:

- ✓ **pH**:______________________________
- ✓ **Organic Matter**:______________________________
- ✓ **Macronutrients (P, K, Ca, Mg)**:______________________________
____
- ✓ **Micronutrients**:______________________________
____

Your Recommendation(s):______________________________

____

____

____

Checklist: Low pH, low organic matter, low Ca, Low P, Low Bo. **Recommendations:** Add Calcitic lime to raise pH, add Ca. Add Phosphorus, Boron, Organic matter.

Exercise 7: Raspberries, Loamy Soil

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	Medium
Calcium (Ca)	Medium
Magnesium (Mg)	Medium
Manganese (Mn)	
Iron (Fe)	
Aluminum (Al)	389
Boron (B)	2.2
Zinc (Zn)	
pH	6.2
Organic Matter	4.9%

Your checklist:

- ✓ **pH**:____________________
- ✓ **Organic Matter**:____________________
- ✓ **Macronutrients (P, K, Ca, Mg)**:____________________
  ____
- ✓ **Micronutrients:**____________________
  ____

Your Recommendation(s):____________________

____

____

____

Checklist: pH, OM ok; macronutrients medium range; aluminum level pretty high. **Recommendation:** Add a small amount P and K; add a slightly higher amount lime than recommended to push pH to high end to make aluminum less available.

A real life example: blueberries

Foreground: blueberry bushes not growing very well, grass mostly dead. Background: bushes performing better, some grass in row middles. What is happening here? Three soil tests were taken in three different age plantings. Photo courtesy C. Heidenreich.

Test Results/Observations:

1994: soil pH 4.7, Al 170, P 4 lb/A—healthy plants, living sod

2001: soil pH 5.2, Al 552, P 6 lb/A—sick plants, dead sod

2003: soil pH 6.6, Al 670, P 12 lb/A—fair plants, living sod

The plants at the higher pH were better off than plants at a lower pH. Why? Aluminum levels in that soil were very high but the aluminum was less available at the higher pH. At the lower pH site, aluminum was more available, hence the toxicity symptoms seen here… Bottom line: This is not a good site for growing blueberries (or any berry crop) because of the inherently high aluminum levels.

Nutrient uptake

Nutrient uptake in soil occurs in 3 different ways: 1) Direct contact with roots, 2) mass flow (water soluble, through transpirational stream) and/or 3) diffusion (short distance transport in water, from higher concentration in soil to lower concentration in the root (*Table 3*).

Nutrients are primarily taken up by contact and diffusion and must be in close proximity to the root itself. Since on average 1% and at most 3% of the soil surface is in direct contact with the root surface, nutrients must be thoroughly incorporated in to soil prior to planting for good uptake. Table 3 gives modes of uptake for various nutrients in corn; these modes are appropriate for most crops.

Table 3: *Modes of uptake (% though each mechanism) for various nutrients in corn.*

Nutrient	Root interception	Mass flow	Diffusion
Nitrogen (N)	1	99	0
Phosphorus (P)	3	6	94
Potassium (K)	2	20	78
Calcium (Ca)	28	72	0
Magnesium (Mg)	13	87	0
Copper (Cu)	3	97	0
Zinc (Zn)	33	33	33
Boron (B)	3	97	0
Iron (Fe)	11	53	37
Manganese (Mn)	20	80	0
Molybdenum (Mo)	5	95	0

Note: nitrogen is mostly taken up by mass flow. Nitrogen (in the nitrate or ammonium forms) gets dissolved in aqueous solution in soil which moves into the root system as the plant transpires; water transpires through the leaf leaving the nitrogen inside the plant. Thus nitrogen may be applied to the soil surface, dissolves and gets to the roots of the plant even after the plant is established. Boron is also very highly soluble and is taken up by mass flow as well.

Other nutrients, such as phosphorus and potassium are taken up by diffusion; they do not rapidly dissolve or move through the soil very quickly, thus they must be well-incorporated in soil.

Once plants are established, a foliar analysis will provide many more clues to help diagnose nutrient problems.

Summary

The goal of soil testing is to estimate the plant-available nutrient levels in soil. Ensuing test results are accompanied by recommended levels of amendments to bring up levels to some optimum for the berry crop of choice.

The most important adjustment to make is soil pH. If pH is not within a desired range, then the ability of the plant to take up nutrients will be compromised. The optimal soil pH range for most crops is between 6.0 to 6.5; at this range most of the nutrients are readily available. The exception to this rule is blueberries where the optimum is 4.5.

Adding lime or sulfur to the soil does not change the pH instantly. Significant time is required for lime or sulfur to affect pH (6 months or longer). The rate of pH change is affected by particle size (smaller-quicker, larger-slower), soil moisture (dry soils- slower, moist soils-faster), temperature (slower in winter, faster in spring, summer, fall), and good aeration as oxygen is needed for the biological process of pH change to happen.

Things to look for when interpreting soil test results include soil pH, organic matter content, macro nutrients (P, K, Ca, Mg), and micronutrients (to a lesser degree). Boron is one of the most commonly observed micronutrient deficiencies in berry plantings. High aluminum levels in soil are often the cause of phytotoxicity at lower pH levels.

Nutrient uptake in soil occurs in 3 different ways: 1) Direct contact with roots, 2) mass flow (water soluble, through transpirational stream) and/or 3) diffusion (short distance transport in water, from higher concentration in soil to lower concentration in the root. Those nutrients such as nitrogen and boron that are taken up directly or by mass flow may be applied to the soil surface. Nutrients taken up primarily by diffusion such as P, K, Ca, and Mg are best mixed thoroughly into soil before planting and rarely need to be applied subsequent to planting.

Additional Resources

1. *Understanding Your Agro-One Soil Test Results*
   http://www.fruit.cornell.edu/berry/production/pdfs/UnderstandingAgro1results.pdf
2. *Leaf and soil tests on local berry farms: Lessons from summer 2010*
   http://www.fruit.cornell.edu/berry/production/pdfs/berrysoilleaftestshaw.pdf

Chapter 4 Correction of Preplant Soil Problems for Berries - *Dr. Eric Hanson, Michigan State University*

This chapter will discuss means of correcting soil nutritional problems for berries, emphasizing preplant considerations. There are a number of things beyond nutrition to be concerned about prior to planting any berry crop. Things to think about that may or may not relate to nutrition:

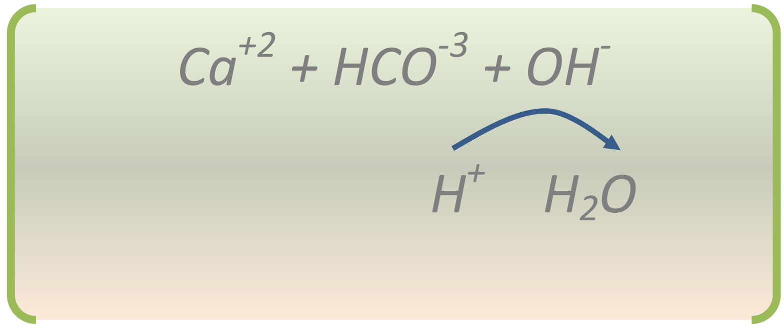
- Have a good appreciation of how soil texture varies across the site. The site may contain one or more soil types. Have an idea where breaks in soil types occur - it may influence how you manage nutrition in coming years.
- Consider the past history of management on the site – was it used for farming for a long time prior to berry crops - would it benefit from cover cops, manure, compost or other organic amendment additions to build OM in soil prior to planting?
- Are there wet spots? This does relate to nutrition to some degree as it interacts with fertility. Are there poorly drained areas? Consider tile draining and/or surface ditching help to get rid of excessive water.
- Have you done an adequate job of soil testing for pH and nutrient levels prior to establishing your plants?

Let's review

Soil analysis laboratories - There are many private and university labs to choose from. Only use the interpretation recommendations from that lab not a different one as methods vary from lab to lab. Make it simple on yourself: pick one lab and stick with it.

Optimum pH range for berries – There are two basic groups of berry crops: *1)* Brambles and strawberries like slightly acidic soils ranging from 6.0 to 6.5 and 2) Blueberries and cranberries which are very acid-loving so way down on pH scale (4.2 to 4.5). The first order of business is getting pH in the range you'd like for these plants.

Preplant pH adjustment



Liming

If pH too low, liming is in order. Lime is calcium carbonate ($CaCO_{3)}$; it dissolves slowly in soil solutions and releases calcium and carbonate anions. There a lot of different liming materials and a number of considerations for choosing the best type.

General benefits of liming

Liming reduces possibility of toxic levels of aluminum and manganese. As pH increases the solubility of these elements declines. Liming supplies calcium and depending on lime source possibly magnesium. It also Increases availability of phosphorus if you are outside of the desired range for crops. Liming increases microbial activity associated with nitrogen fixation (legumes perform better at higher pH) and nitrification (oxidation of ammonium to produce nitrate); microbes for this prefer higher pH. In addition, organic matter decomposition and nitrogen mineralization tend to be promoted by more neutral pH ranges.

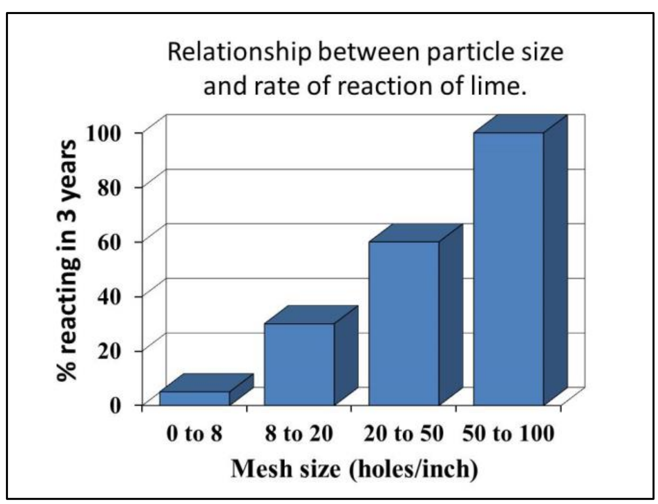
How to choose a lime source

Ask yourself the following questions when selecting a lime source to use to lower pH. First, what is the neutralizing value (calcium carbonate, $CaCO_3$ equivalent) of the product you are considering and how effective it is in increasing pH? (*Table 4*).

Table 4. *Neutralizing value of liming materials (as compared to pure $CaCO_3$)*

Material	Neutralizing value
Calcium carbonate (CaCO3)	100
Dolomitic lime	95-108
Calcitic lime (High-Cal lime)	95-100
Hydrated lime	120-135
Marl	50-90
Gypsum (CaSO4)	0

Second, what is the reaction rate (dictated by particle (mesh) size of the product; in other words, how fast does it react in soil? Is there a need for supplemental magnesium also that may be supplied as part of the lime product selected? What's the product cost, ease of application, and availability in your location?



An additional consideration is the speed of reaction of the various materials which is dictated by particle size as a function of available surface area (*right*). Smaller mesh size equals larger particles. A mesh size of greater than 20 reacts fairly well within year or 2 in soils. Eight to twenty mesh size particles react very slowly, less than half has reacted in 3 years; zero to eight mesh size particles are almost inert. When you think of value of lime material product contains high percentage of these size particle sizes pretty much worthless in terms of fast reaction.

Marl is a kind of lime mud, mined in different locations; it tends to vary greatly in liming capacity. Gypsum contains calcium but is not a liming material; it has no effect on soil pH.

Another type of lime used in fruit production in various areas is pelleted lime, “Pell-Lime”, a finely ground (smaller than 100 mesh) Calcitic or Dolomitic lime formed into 4-20 mesh size pellets using binders. Pell-lime generally reacts about as quickly and neutralizes the same amount of acidity as an ag-lime with similar neutralizing values. Pell lime is easier to apply and handle and wind-blown losses may be less. That being said, it is much more expensive than most ag-lime; you are paying more for all that convenience…

Lowering soil pH

Lowering soil pH is not usually desired except on blueberry sites where pH is above 5.0. In some instances, however, lowering soil pH may be desirable with other berry crops (strawberries and raspberries) where pH is 6.5 or above. This may be the case on sites with naturally occurring alkaline soils and/or a history or lime applications associated with agronomic crop production.

Acidifying agents

There are a number of materials for lowering soil pH but sulfur is the material of choice to use. Elemental sulfur, depending on the brand, comes as prills, chips, or powders; ranging from 90-95% sulfur. So if the recommendation is 500 lb/acre sulfur then you would want to increase the application by 5-10% to compensate. Prills easiest to use, being low in dust and easy to spread with fertilizer spreader. Chips are intermediate in ease of use, come in lots of different sizes and tend to be dusty during application. Powdered sulfur is difficult to use altogether, being extremely dusty, except perhaps in a back yard situation where a small quantity is needed.

Iron sulfate is a salt that also reduces pH and reacts quickly in soils, but is more expensive than sulfur because 6 times as much is required for same pH reduction. Its use may also result in salt stress.

Aluminum sulfate is pretty much the same as iron sulfate reacting quickly in the soil but also requires high rates and may result in aluminum toxicity.

Sometimes people think about using acidifying N fertilizers to reduce pH. Ammonium sulfate is a very acidic N fertilizer; it helps to maintain pH low but should not be used to reduce pH initially as it will result in excessive N. For example 1 lb sulfur provides same acidity as 2.8 lb ammonium sulfate $(NH_4)_2SO_4$ so if the recommendation is for 500 lb/A sulfur the equivalent $(NH_4)_2SO_4$ would provide 294 lb/A N! This would be neither efficient in terms of nutrient use nor cost effective.

A little bit about sulfur…

Sulfur is oxidized by a specific group in bacteria in soil thus its pH lowering function is a biological process. As such, nothing much happens during off season when soils too cold for the bacteria to work. Sulfur lowering of soil pH occurs best in moist, warm, aerated soils; bacteria oxidize sulfur to sulfuric acid. The reaction requires the better part of an entire growing season (year) to occur. Apply sulfur the year before planting; it’s important is to incorporate it well for the quickest reaction.

Sulfur may be broadcast over a site (recommended) or banded in planting rows. For heavier, highly buffered soils, it is most economical to do this where bushes will grow as one only needs apply perhaps half the sulfur amount needed as compared to broadcast application.

Soil types are instrumental to the amount of sulfur needed to drop pH; 2-3 times as much needed to drop it on a loam vs. sand; 4-5 times as much for a clay soil as opposed to a sand (*Table 1*). It may not be economical to produce blueberries on a soil with high pH that is also a highly buffered soil as it would take so much sulfur to get to proper pH.

Cautions

If applying more than 500 lb/acre sulfur, split the application. Apply half in the season prior to planting and the remaining half in spring prior to planting so its reacting in soil at 2 different times. It is important to note sulfur produces hydrogen sulfide on poorly drained soils and is toxic to plant roots. Toxic levels could develop in those areas due to anaerobic conditions in the root zone.

Preplant phosphorus use

Incorporate phosphorus (P) prior to planting at rates indicated by soil test results. Choose materials based on coast per unit of P_2O_5 and the percent availability of P from the materials (*Table 6*). Standard materials such as superphosphate and concentrated superphosphate are readily available (100% soluble); the choice between these is based on pricing per unit P.

Table 6. *Sources of phosphorus*

Fertilizer	Total P_2O_5%	% P available
Superphosphate	21	96-100
Concentrated superphosphate	45	96-99
Rock phosphate	34	3-8

Rock phosphate the (mineral other P fertilizers are manufactured from) is fairly high in P but very low in soluble P. It may have some utility in organic settings but also in blueberry settings where you want a slow release of P over time. In high pH soils, rock phosphate would be non-effective as its solubility goes down as pH goes up; in acidic soils this might be a nice material to supply a gradual release of P over time as long as pH remains low.

Diammonium and/or mono-ammonium phosphate doesn't make much sense preplant as you typically don't want to be putting a large amount of N in soil preplant; they are also very, very expensive sources of P unless you need the N also.

Preplant potassium

Incorporate potassium (K) prior to planting at rates indicated by soil test results. Choose potassium materials based on cost per unit of K_2O, the need for other nutrients, and the potential hazard from chloride if considering the use of muriate of potash (most cost effective) as your K amendment source (*Table 7*). The potential hazard from chlorine (muriate) if applying low levels (<200 lb/A) is minor and probably safe on most of these crops. If muriate is the material of choice (lower price) on a sandy soil, and there is a concern about chlorine toxicity, apply it in fall so most of chlorine anions leach out of root zone during the winter to reduce potential risk.

Table 7. *Sources of potassium*

Fertilizer	% K_2O	Cost per unit K_2O
Potassium chloride (muriate of potash)	60-62	$
Potassium sulfate (SOP)	50-54	$$
Potassium-magnesium sulfate (Sul-Po-Mag)	22 (11% Mg)	$$$

Preplant magnesium and calcium

Again, incorporate magnesium (Mg) and calcium (Ca) prior to planting at rates indicated by soil test results. Choose Mg and Ca materials based on cost per unit of Mg or Ca, the need for pH adjustment up or down, and then the need for other nutrients (Table 8). The cheapest sources for Mg and Ca are the limestones (calcitic lime, dolomitic lime); these are good choices for increasing pH. Ratios of Ca and Mg in these limes vary with the source of the materials.

If there is a need to add Mg but not increase pH then magnesium sulfate would be the material of choice. If calcium is needed without increasing pH then calcium sulfate (gypsum) is a good option Magnesium low also? Consider Sul-Po-Mag; it has a higher K_2O cost per unit but may still be a good choice economically as it contains both K and Mg.

Table 8. *Sources of magnesium and calcium*

Fertilizer	% Mg	% Ca	% K
Magnesium sulfate	10		
Calcium sulfate (Gypsum)		22	
Potassium-magnesium sulfate	11		22
Calcitic lime	< 5	> 30	
Dolomitic lime	>5	<30	

Gypsum

Gypsum supplies calcium but does not alter pH. This product is known to be very beneficial on soils high in salts (sodic soils) where it improves flocculation (adhesion) of clay particles and thus improves water infiltration/drainage. Sodic soils are not typically found in eastern US as this region tends to be a humid environment with ample precipitation most of the time.

However, another interesting fact about gypsum is that it has also been shown to reduce raspberry root rots caused by Phytophthora species in NY (*Maloney et al., 2005*) and to some extent in Washington trials (*Pinkerton et al., 2009*).

Gypsum was also demonstrated to reduce Phytophthora diseases of avocado (*Messenger et al*., 2000), soybean (*Sugimoto et al*., 2010) and ginseng (*Maloney et al.,* 2005).

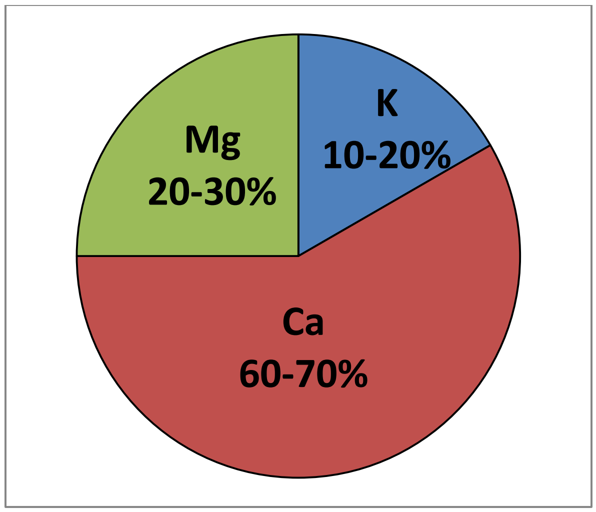
These are different fungal species and the gypsum seems to benefit the plants in each regard. This is not an effect of calcium on soil drainage or physical properties but is apparently due to the inhibitory effect of high calcium concentrations on fungal growth and infection of plant tissues, along with reproductive rate of the fungi.

The recommendation from the NY work with raspberries is to incorporate 3-6 tons of gypsum prior to planting raspberries on sites with a history of Phytophthora root rot.

Potentially then, enhancing free calcium levels in soil with gypsum would reduce incidence of other Phytophthora diseases; for example, red stele disease of strawberries.

A related question would be whether you get the same response if you are working with soil that is naturally high in calcium. That is unknown at this point. In Michigan we think about a balance of Ca, Mg and K in soils. This is expressed as a balance of total bases on the cation exchange complex in soil (*Figure 7*).

Figure 7. *Desired ranges for % of bases*



Salt stress

Salt in water reduces its water potential, making it less available to plants, causing them to be water stressed. High soil salt levels tend to be a problem in western arid regions, and are much less common in humid areas where precipitation tends to leach salts out of the top soil horizons (i.e. eastern US states). However, growers can create salt problems in soils by using fertilizers inappropriately (excessive use, application of inappropriate types of fertilizers at the wrong time) or by using a high-salt irrigation water source. Salty water conducts electricity; this makes measurement of soil salinity possible using electrical conductivity or EC.

Berry crops are among the least tolerant of elevated salt levels in soil. Table 9 below gives EC readings for various fruit crops. Tree fruits tend to be more tolerant than blackberries, raspberries or strawberries. Blueberries were not included in this listing but would likely fall at or below the same levels as raspberries and strawberries or perhaps be even more sensitive to high salts.

Table 9. *Soil salt levels based on saturated paste extract potentially causing yield reductions in fruit crops.**

Crop	Soil EC** (dS/m)***
Olives	2.7
Grapefruit	1.8
Apple/pear/peach	1.7
Apricots	1.6
Grapes	1.5
Blackberries	1.5
Raspberries/strawberries	1.0
Blueberries	<1.0

*Western Fertilizer Handbook (1990).

**EC Electrical conductivity

***1 dS/m = 1mmho/cm

The effect of fertilizers on salt content of soil has been well-documented; it's expressed as salt index. Table 10 lists some of the more common N fertilizer sources and their salt indices. Quite often published values for salt indices of fertilizers are essentially expressed per unit fertilizer not per unit nutrient. So although ammonium nitrate has a very high salt index of 105, it contains a higher concentration of N than some other nutrient sources. So if one extrapolates that salt index on a per unit nitrogen basis (lb N), the potential for salt injury would be less than with calcium nitrate. The assumption being if you desired to apply desired a certain amount of N you would contribute less salt per the amount of N using ammonium nitrate than you would with calcium nitrate - even though calcium nitrate is often touted as being more safe fertilizer from a salt standpoint.

Table 10. *Salt index values for some common nitrogen fertilizers*

Fertilizer	% N	Salt Index*	Salt Index per Unit N
Ammonium nitrate	33	105	300
Ammonium sulfate	21	69	328
Calcium nitrate	12	53	442
Di-ammonium phosphate	18	29	161
Mono-ammonium phosphate	11	27	245
Natural organic	13	3.5	70
UAN 28%	28	71	222
Urea	46	75	162

*Salt index is the increase in osmotic pressure resulting addition of fertilizer to a solution, relative to effect of the same amount of $NaNO_3$ (SI = 100).

Table 11 provides salt indices for some common P and K fertilizers. For the most part phosphorous fertilizers are relatively low in salt indices except for ammoniated phosphates. With potassium fertilizers chloride has a higher risk of salt injury.

Table 11. *Salt index values for some P and K fertilizers*

Fertilizer	% Nutrient	Salt Index*	Salt Index per Unit Nutrient
P2O5			
Superphosphate	20	8	39
Concentrated superphosphate	45	10	22
Mono-ammonium phosphate	11	27	245
Di-ammonium phosphate	18	29	161
K2O			
Potassium chloride	63	114	181
Potassium sulfate	54	46	85

*Salt index is the increase in osmotic pressure resulting addition of fertilizer to a solution, relative to effect of the same amount of NaNO3 (SI = 100).

Organic nitrogen sources

There are a lot of different sources of organic nitrogen (*Table 12*). Some of the higher N content sources include dried blood, fish meal, and nitrate of soda. Be sure to check with you certifier for which types of these they accept. Good phosphorous sources would be bone meal or fish meal; kelp and wood ash are potassium sources.

Table 12. *Nutrient content of some common organic nutrient sources**

Material	N	P2O5	K2O
Bone meal (steamed)	1-2	18-34	--
Compost	1-3.5	0.5-1.0	1-2
Cotton seed meal	6	2.5	1.7
Dried blood	12	1.5	0.6
Fish emulsion	5	2	2
Fish meal	14	4	1
Kelp	1	0.5	4-13
Marl		2	4.5
Nitrate of soda	16	--	--
Rock phosphate	--	3	--
Soybean meal	7	2	2
Wood ash	--	1-2	3-7

Preplant manure and compost addition

This has a lot of significance now with given the increasing prices of nitrogen fertilizer which have doubled in the last decade. Prices for two common phosphates and potassium chloride have more than doubled (*Figures 8a and 8b*).

Figure 8a. *Average nitrogen fertilizer price trends in the US*

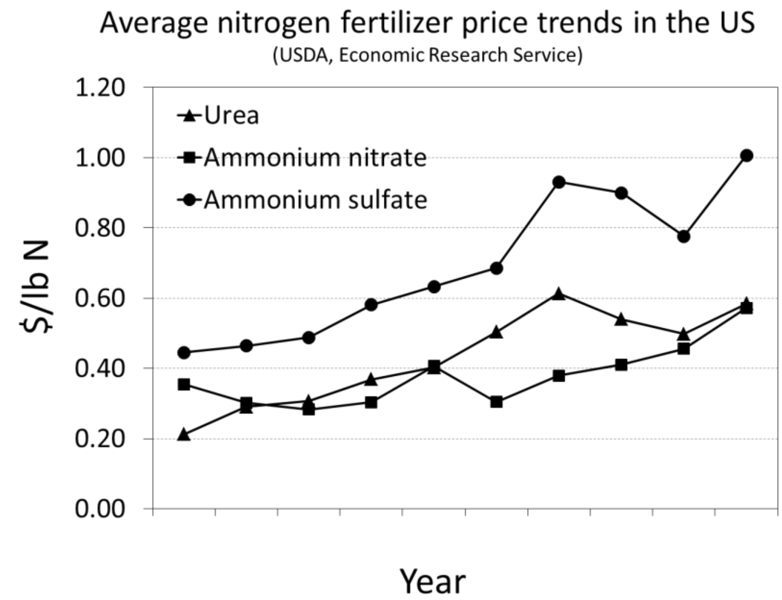
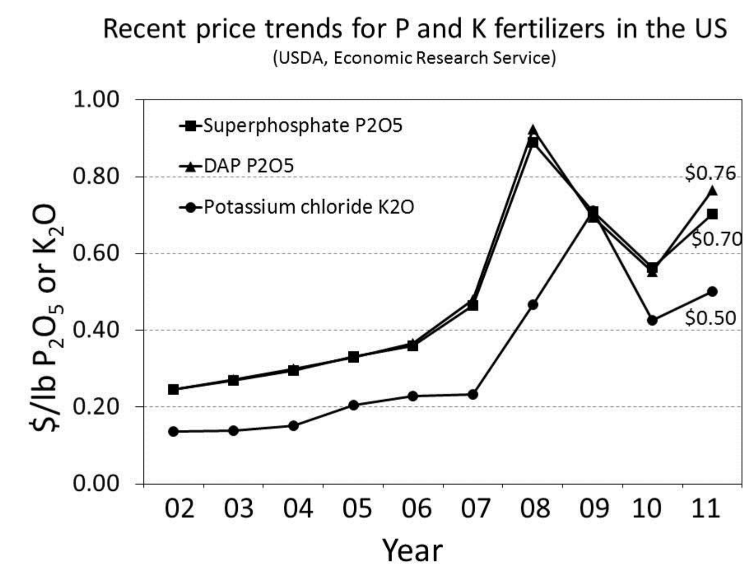


Figure 8b. *Recent price trends for P and K fertilizers in the US*



Manure and/or compost additions are beneficial, particularly on sandier soils or heavily farmed sites to provide nutrients, increase soil organic matter and improve soil structure. Apply and incorporate raw manure in the fall before spring planting. Table 13 provides a short list of different manures types and their nutrient content in pounds per ton.

Any material to be applied should be analyzed prior to application to avoid excessive total salts, excessive P, N tie-up or excess, and/or specific element toxicities (heavy metals such as boron, sodium or chloride). Avoid manure or compost with salt levels > 10 dS/m. Apply materials with moderate salt levels in the fall to allow salts to leach.

Table 13: *Manure nutrient content (lb/ton)**

Material	NH_4-N	Total N	P_2O_5	K_2O
Swine, no bedding	6	10	9	8
Beef, no bedding	7	21	14	23
Dairy, no bedding	4	9	4	10
Dairy compost	<1	12	12	26
Poultry, w litter	36	56	45	34
Poultry compost	1	17	39	23
Turkey w litter	13	20	16	13

**From: Rosen and Bierman. Univ. Minn. Ext. Bul. M1192.*

Summary

There are a number of things beyond nutrition to be concerned about prior to planting any berry crop. Things to think about that may or may not relate to nutrition include:

- Have a good appreciation of how soil texture varies across the site. The site may contain one or more soil types. Have an idea where breaks in soil types occur - it may influence how you manage nutrition in coming years.
- Consider the past history of management on the site – was it used for farming for a long time prior to berry crops - would it benefit from cover cops, manure, compost or other organic amendment additions to build OM in soil prior to planting?
- Are there wet spots? This does relate to nutrition to some degree as it interacts with fertility. Are there poorly drained areas? Consider tile draining and/or surface ditching help to get rid of excessive water.
- Have you done an adequate job of soil testing for pH and nutrient levels prior to establishing your plants; if so, have you made the recommended amendments?

Additional resources

1. Pritts, M. 2012. Site and Soil Requirements for Berry Crops http://www.fruit.cornell.edu/berry/production/pdfs/sitesoireqsmfru.rev.pdf
2. Pritts, M., and Hancock, J. (eds.) 1992. “Nutrient Management” Chapter 11 in: Highbush Blueberry Production, Plant and Life Science Publishing, Ithaca, NY. 200 pp. Fair use copy available in pdf format: http://host31.spidergraphics.com/nra/doc/Fair%20Use%20Web%20PDFs/NRAES-55_Web.pdf
3. Bushway, L., Pritts, M. and Handley, D. (eds.) 2008. “Soil and Nutrient Management”, Chapter 7 in: Raspberry and Blackberry production Guide for the Northeast, Mid-West and Eastern Canada. Plant and Life Science Publishing, Ithaca, NY. 157 pp. Fair use copy available in pdf format: http://host31.spidergraphics.com/nra/doc/Fair%20Use%20Web%20PDFs/NRAES-35_Web.pdf
4. Pritts, M., and Handley, D. 1998. Soil and Nutrient Management”, Chapter 7 in: Strawberry production Guide for the Northeast, Mid-West and Eastern Canada. Plant and Life Science Publishing, Ithaca, NY. 162 pp.
5. Hanson, E. and Hancock, J. 1996. Managing Nutrition of Highbush Blueberries. Michigan State University Extension Bulletin E-2011, 8 pp.

Chapter 5 Foliar Testing and Sampling in Berry Crops, Visual Symptoms of Deficiencies - *Dr. Marvin Pritts, Cornell University*

Let's review

Soil testing is most useful prior to planting to adjust pH and nutrient levels. Leaf analysis is most appropriate once the planting is established. Determining what the plant itself has taken up is a more accurate assessment of nutrient status than estimating availability in soil using a chemical extractant, which only mimics what the root may take up from soil. Foliar testing is particularly important for perennial plants that may accumulate and store up nutrients over a period of years.

Foliar analysis – a simple principle

Foliar analysis is based on a simple principle where nutrient levels in the leaf tissue are compared to a pre-determined standard. Similar to a cholesterol test at the doctor's office, your level is compared to a normal range and if it's too high or too low, appropriate steps are taken to adjust it accordingly. Standard leaf nutrient ranges have been established for many crops including berry crops such as strawberries (*Table 14*).

Table 14. *Standard foliar nutrient ranges for strawberries*

Element	Range (PPM)	Element	Range (PPM)
Nitrogen (N)	2.0 – 2.8	**Manganese** (Mn)	50 - 200
Potassium (K)	1.5 – 2.5	**Iron** (Fe)	60 – 250
Phosphorus (P)	0.25 – 0.40	**Copper** (Cu)	6 - 20
Calcium (Ca)	0.7 – 1.7	**Boron** (B)	30 – 70
Magnesium (Mg)	0.3 – 0.5	**Zinc** (Zn)	20 – 50

What is the basis for these standard nutrient ranges? The analysis for leaf tissue, unlike soil analysis with its various extractants, is the same from lab to lab as it is based on inductively coupled plasma spectrometry (ICPS). A specified amount of leaf tissue is heated to really hot temperatures; the various minerals present in the tissue glow different colors as they are heated. The spectrophotometer measures the resulting color ranges, spectra, and intensities, correlating these with the amount of a specific element present in the tissue.

Nitrogen and sulfur are the exceptions to ICPS testing. These minerals are better tested using other methods including digestion and methods of quantifying amounts present such as colorimetric spectrophotometry, specific ion electrodes and/or combustion. Results from these methods are pretty closely correlated so not of concern. This is especially true for sulfur, particularly as it is rare to have a sulfur deficiency.

The most desirable method for nitrogen would be to determine the amount of biologically active nitrogen (NH_4+) as opposed to NO_3- or total N but determining NH_4+ is expensive ; the nitrate (NO_3-) concentration in plants is pretty low, thus using total N is the least expensive method for evaluating N and assuming it is highly correlated with the biologically-active NH_4+.

Standard tissue ranges used today are derived from healthy plants; they are not usually empirically derived. That means they are not a result of nutrient experiments where plant response is measured to various nutrient levels. To do this type of testing for each crop and nutrient would be entirely too time-consuming and expensive.

Instead, they are an average of those values obtained from testing a large pool of healthy leaf samples for a given crop.

When should leaf samples be taken?

It is important to note leaf samples should be taken at a time when leaf nutrient values are relatively stable. The time to sample is not when plants are growing rapidly in spring or when fruit expansion is ongoing as leaf nutrient levels may change rapidly during these times and not be representative. For strawberries, the best time to sample for leaf analysis is after harvest at renovation when the new leaves begin to grow in late July to early August. For either summer or fall-bearing raspberries, the best time for sampling would be in early August when most of the rapid plant growth is completed for both and summer raspberries have finished fruiting and fall raspberries haven't begun fruiting. For both it is best to sample leaves from primocanes. August is also the best time to sample blueberries for the similar reasons.

Which leaves should I select?

Select the most recently mature leaves for analysis are the best indicator of nutrient status. Older leaves are those produced during the period or rapid growth or fruit expansion and may not be representative. Collect 30 to 50 leaflets without petioles. Randomly sample the area of interest. This may be done on a diagnostic basis (plants not performing well or on a routine basis routine to document nutrient status. Choose young leaves exposed to sun.

How do I prepare collected leaves for analysis?

Rinse in distilled water to remove dust, soil or fungicide residues. Dry for a couple days in a brown paper bag before sending to the lab. There is no need for the leaves to be kept moist and/or green as they may begin the decomposition process in transit to the lab. They are routinely dried prior to testing so it's best to begin the drying process immediately. There's also no need for rapid drying using heat or fans; just room temperature drying on a non-metal surface will suffice.

Advantages and shortcomings of foliar testing

Foliar analysis offers some major advantages, not least of which is the standardization of analyses across labs. Foliar analysis is also a better indicator of nutrient status than a soil test. Additionally, it can identify a potential nutrient deficiency to be redressed ***before*** it results in visible symptoms or reduced growth and yield. Leaf analysis can also be used to help in crop diagnostics; often nutrient problems may have similar symptoms to those caused by diseases and/or pests; leaf analysis may be used to confirm or rule out deficiencies as a probable cause.

Some of the shortcomings of foliar testing, while relatively minor, include the fact it provides the total amount of an element, not the amount that is biologically active. Iron is probably one of the most important of these. For example, Fe^{++} is the active form for plants vs. Fe^{+++} which is not as biologically active; unfortunately the ICPS gives only a value for total iron. Thus there may be an iron deficiency occurring even when the leaf analysis indicates sufficient iron is present. Another shortcoming is that the prescribed sampling time of late July to early August when these elements are most stable may not be most ideal for all elements. Additionally, leaf analysis does not negate the need for a soil test; rather, an accompanying soil test is needed for leaf analysis results to be meaningful as they are soil pH dependent. And finally, leaf analysis does not measure interactions among elements that can affect activity and bioavailability. Examples of this include: 1) High potassium (K) levels in the plant decreases Magnesium (Mg) activity, 2) iron (Fe) and phosphorus (P) are antagonistic, 3) zinc (Zn) and phosphorus (P) are antagonistic and 4) Calcium (Ca) and iron (Fe) are antagonistic in blueberries.

A caveat to our discussion of nutrient deficiencies is that frequently more than one nutrient is deficient at a time. Usually the conditions that affect the level of a specific nutrient can impact multiple nutrients simultaneously. For example, a high pH from an improper lime application can induce deficiencies of iron, manganese, copper, boron, zinc and phosphorus.

The role of essential nutrients in plant growth and development

Nutrients play many roles in essential plant functions (*Table 15*). Potassium is the only one of these essential elements not directly incorporated into plants. Note however it is important in catalyzing more than 50 enzymatic reactions in plants, and in osmoregulation.

Table 15. *Essential elements in plants and their functions*

Element	Function
Nitrogen (N)	Amino acids; cation-anion balances; osmoregulation
Phosphorus (P)	DNA/RNA structure; energy transfer; metabolism
Potassium (K)	Osmoregulation; metabolism; enzyme activation (50+); photosynthesis
Calcium (Ca)	Cell walls; cell extension; enzyme modulation, vacuole pH
Magnesium (Mg)	Chlorophyll; protein synthesis; enzyme activation; vacuole pH
Manganese b	Oxygen evolution; enzyme activation
Iron (Fe)	Chloroplast development; redox systems; protein synthesis
Copper (Cu)	Strongly bound; lignification; enzyme activation; pollen formation
Boron (B)	Cell elongation; lignification; xylem differentiation; auxin activity
Zinc (Zn)	Root cell elongation; pollen germination

Other essential nutrients in plants are among the most recently discovered due to the difficulty in working with them in the small amounts required in a laboratory setting. These include Molybdenum, Chlorine and Nickel. Sodium, Selenium, Cobalt and Silicon are essential nutrients for some plants and/or plant families; but not for berry crops. In the case of Sodium and Selenium they may have a negative impact on berry crops if present in excess. Table 16 shows the relative concentrations for essential elements in plants.

Table 16. *Adequate relative concentrations of elements in healthy plant tissue.*

Element	Atoms	Element	Atoms
Nickel (Ni)	1	Silicon (Si)	30,000
Molybdenum (Mo)	1	Sulfur (S)	30,000
Cobalt (Co)	2	Phosphorus (P)	60,000
Copper (Cu)	100	Magnesium (Mg)	80,000
Zinc (Zn)	300	Calcium (Ca)	125,000
Sodium (Na)	400	Potassium (K)	250,000
Manganese (Mn)	1000	Nitrogen (N)	1,000,000
Boron (B)	2000	Oxygen (O)	30,000,000
Iron (Fe)	2000	Carbon (C)	40,000,000
Chlorine (Cl)	3000	Hydrogen (H)	60,000,000

One of the challenges of leaf analysis is coming up with a test that measures various elements across such a wide, wide range of concentrations. For example Nickel at 1 atom and Iron at 2,000, vs. Magnesium at 80,000 and Carbon at 40,000,000. We are fortunate to have technology capable of doing so today.

Visual symptoms of nutrient deficiencies

It is important to note that certain nutrients (N, P, K, Mg, and S) are extremely mobile in the plant; this characteristic can help diagnose visual symptoms that you might see. Mobile nutrients tend to move from leaves into the phloem and then to actively growing points; therefore older leaves exhibit deficiencies first. When older leaves exhibit odd colors or look strange and new leaves appear healthy then most often it's the result of a deficiency in N, P, K, Mg, or S. If you see the opposite, where younger leaves look oddly colored or showing deficiencies while older leaves look healthy, most likely it's one of the other essential micronutrients, not N, P, K, Mg, or S.

Table 17 below gives nutrient ranges for sap. Remember, xylem is what comes up from the roots into the leaf; phloem is what comes out of the leaves. For example, there may be no sugar in the xylem; but lots of sugar coming out of the phloem. Nitrate is the reverse of sugar in this respect. It moves from the soil water into the roots then the leaves; none of it comes out of the phloem during the growing season. Nitrate doesn't move through the phloem; in the leaf it's converted by nitrate reductase into amino acids and/or ammonium compounds.

Table 17. *Typical nutrient ranges for plant sap*

Element	Xylem (mg/L)	Phloem (mg/L)
Sugars	0	140,000 – 210,000
Amino Acids	200 – 1,000	900 – 10,000
Ammonium (NH_4+)	7 – 60	45 – 846
Nitrate (NO_3-)	1500 – 2000	0
Phosphorus (P)	70 – 80	300 – 550
Potassium (K)	200 – 800	2,800 – 4,400
Calcium (Ca)	150 – 200	80 – 150
Magnesium (Mg)	30 – 200	100 – 400
Boron (B)	3 – 6	100 – 400
Manganese (Mn)	0.2 – 0.6	0.9 – 3.4
Copper (Cu)	0.1 – 2.5	1 – 5

There has been some work on determining nitrogen needs by measuring petiole (xylem) sap concentrations of nitrate. This has been done particularly with strawberry to see if a good correlation exists. The problem is that nitrate sap concentration is not necessarily correlated with the amount of active N (amino acids and NH4- are in the phloem). The nitrogen is coming in, but not going out of the plant. Moreover, the nitrate concentration is very dependent on the water flow in the xylem; values change on a day–to-day basis. For this reason this test has not really caught on in perennial crops like berries, as it has in annual crops like corn (but see page 156).

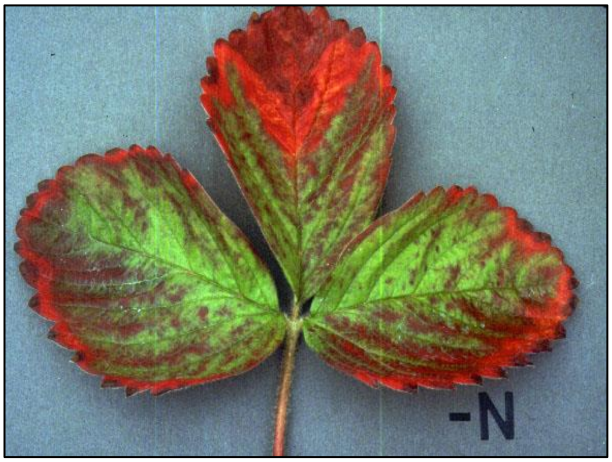
Phosphorus comes into the plant at a low concentration in the xylem and goes out of the leaf through phloem at a relatively high concentration, and is not very mobile. Potassium is very mobile, but calcium is not. When looking for deficiencies of Ca, they are found at the extremities of the plant.

Examples

Nitrogen deficiency. Nitrogen deficiency often appears on the plant as lighter green leaves; in the case of blueberries nitrogen deficient leaves are smaller, yellower in color (*Figure 9a*). Nitrogen deficiency in strawberries has a slightly different appearance (*Figure 9b*) with leaf yellowing moving into reddening.

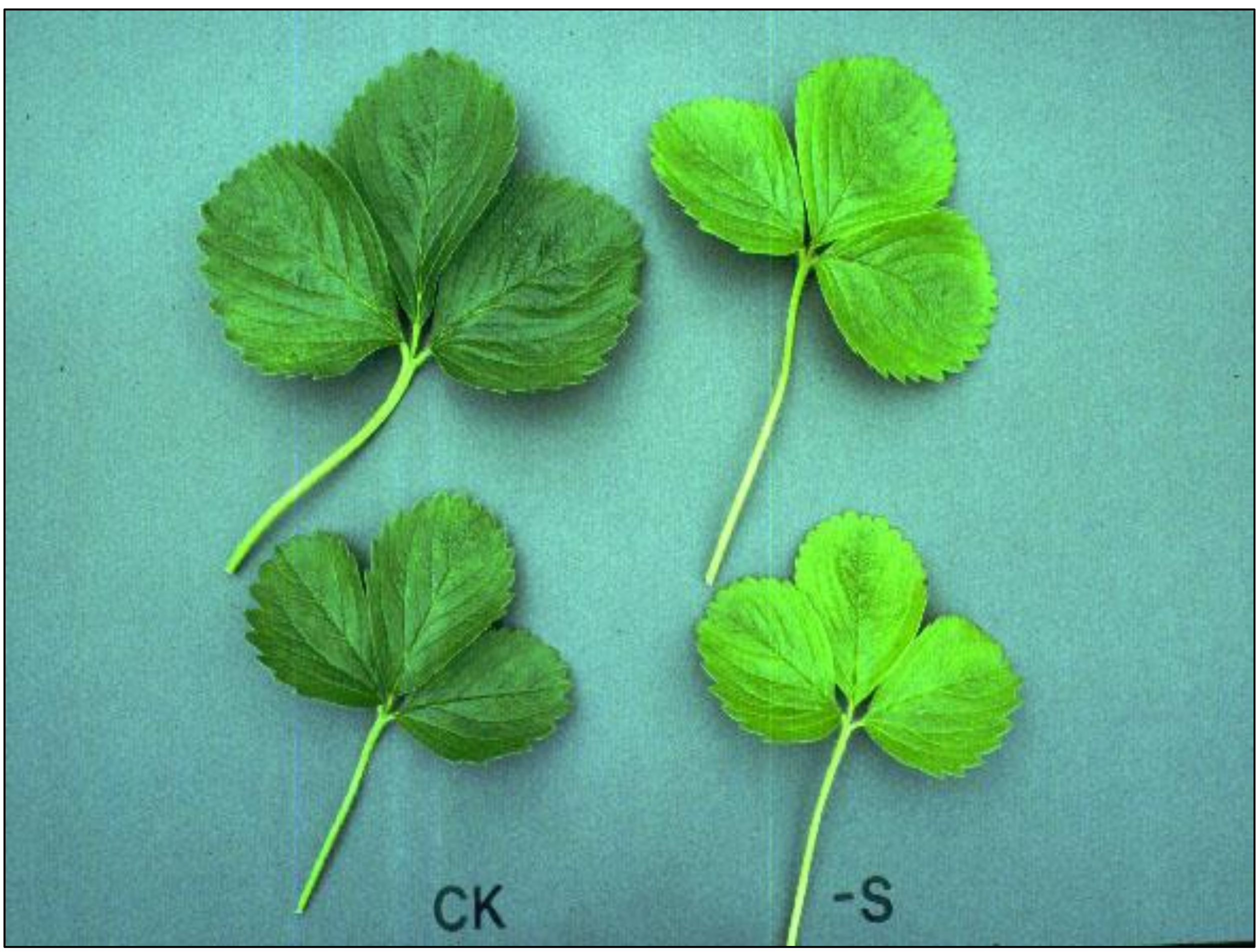
Figure 9a. *Blueberries (left) – healthy (left side of photo) vs. nitrogen deficient (right side of photo). Photo courtesy M. Pritts.*

Figure 9b. *Nitrogen deficient strawberries in complete nutrient solution minus N (left) and in the field, after harvest without N application, (right); note reddening in strawberries. Photos courtesy Michigan State Univ.*



Sulfur deficiency. Sulfur is a deficiency that mimics nitrogen (*Figure 10*); both are essential for amino acid formation. Sulfur and sulfates are ubiquitous in soils so sulfur is not a common deficiency. It occurs most frequently on very sandy soils with high rainfalls.

Figure 10. *Sulfur deficient strawberry leaves from plants in complete nutrient solution minus S (right) and in the complete nutrient solution plus S as a control (left). Photo courtesy M. Pritts.*



Phosphorus deficiency. P deficiency is characterized by darker green colored leaves with dark red coloration developing around leaf margins (*Figures 11a and 11b*). Not particularly common in the NE region where there is a lot of dairy manure spread on fields. Symptoms will appear in the older leaves first. Note: during cold springs, blueberries often develop similar coloration; this disappears as temperatures warm. Do not mistake this for P deficiency in blueberries.

Figure 11a. *Phosphorus deficient strawberries in complete nutrient solution minus P. Photos courtesy M. Pritts.*

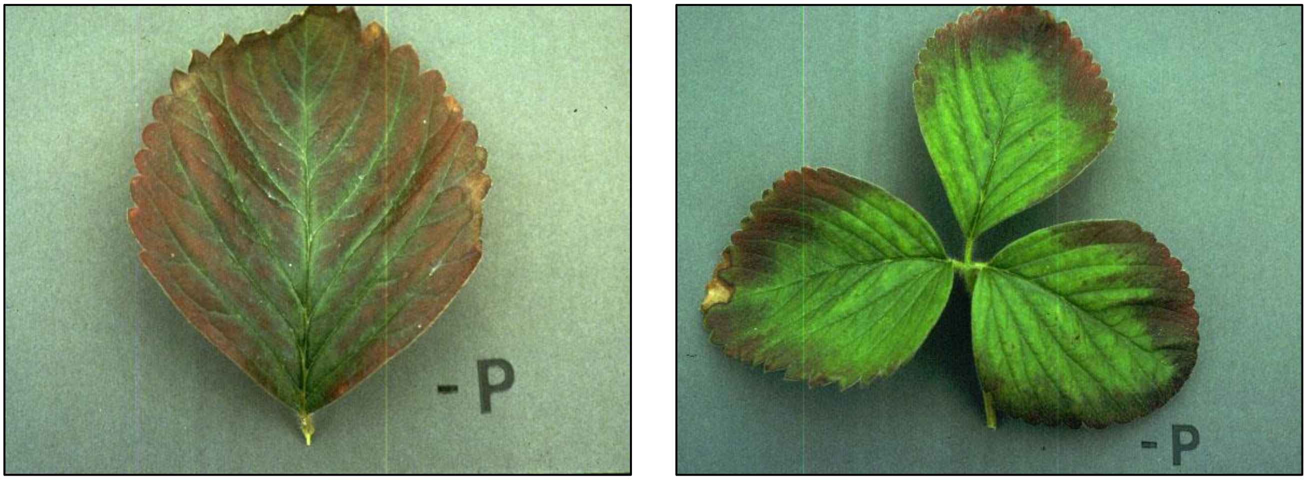
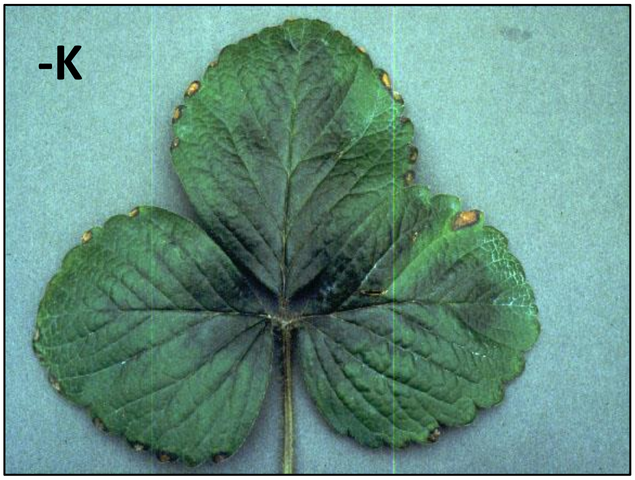


Figure 11b. *Phosphorus deficiency symptoms on blueberry in the field. Photo courtesy M. Pritts.*

Potassium deficiency. K deficiency is more common than P. Slight browning where leaflets attach to petioles is pone symptom of this deficiency. Another is leaves have a light and dark green blotchy appearance (*Figure 12a*); this is often followed by margin burning of leaves (*Figure 12b*). For blueberries, marginal burning is observed (*Figures 12c and 12d*). Remember symptoms will appear on older leaves first.

Figures 12a, 12b. *Potassium deficient strawberries in complete nutrient solution minus K (left) and in the field, (right).*



Figures 12c, 12d. *Potassium deficiency symptoms on blueberry in the field. Photos courtesy M. Pritts.*

Calcium deficiency. Symptoms of this deficiency (*Figures 13a, b, c*) include growing points of leaves turning brown and leaf cupping as leaf tips are not able to expand at same rate as older portion of leaves.

Figures 13a, b, c. *Strawberries with calcium deficiency; leaves (left), growing points (center), and runners (right). Photos courtesy M. Pritts.*

Another symptom to look for is growing points turn blackish brown even before new leaves begin to expand. The symptom to look on strawberry runners is necrosis/browning of runner tips. Calcium deficiency may sometimes result from irregular or lack of irrigation. New growth displays symptoms before older leaves.

Magnesium deficiency. Symptoms of magnesium deficiency are similar to those for calcium but Mg is more mobile in plant than Ca. Mg deficiency symptoms are characteristically interveinal in all plants; green veins with reddish interveinal areas (*Figure 14a*). On strawberry, note that there is no reddish interveinal color, but interveinal browning (*Figure 14b*). New growth displays symptoms before older leaves.

Figures 14a, 14b. *Blueberry leaf showing magnesium deficiency in the field (left), strawberry leaves from plants grown in complete media minus Mg showing deficiency symptoms (right). Photos courtesy M. Pritts.*

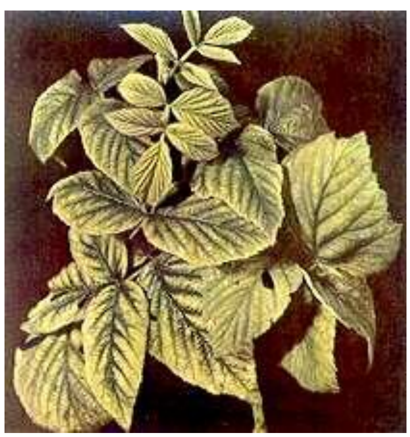
Iron deficiency. Iron deficiency shows up in the younger leaves while older leaves look fine. Yellowing associated with iron deficiency (aka “iron chlorosis”) occurs in interveinal areas while the veins stay green (*Figures 15a, b, c*).

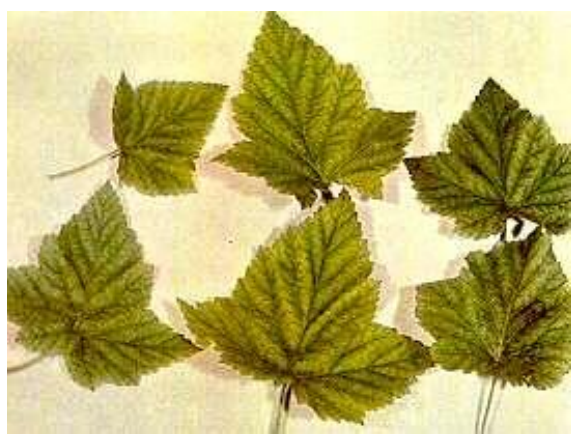
Figures 15a, 15b. *Iron deficiency symptoms in strawberry. Photos courtesy M. Pritts.*

Figure 15c. *Iron deficiency symptoms in blueberry. Photo courtesy M. Pritts.*

Manganese deficiency. This deficiency is not seen very much; when it does occur it is evident on younger leaves first. Mn deficiency symptoms are similar to those observed with iron deficiency but veinal areas are darker. This deficiency is often occurs under circumstances of too high pH; thus blueberries rarely show signs of this deficiency (*Figures 16a, 16b*)

Figures 16a and 16b. *Magnesium deficiency in strawberry (left), raspberry (center), and black currant (right). Photos courtesy: Wallace, T. 1951. [The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms].*





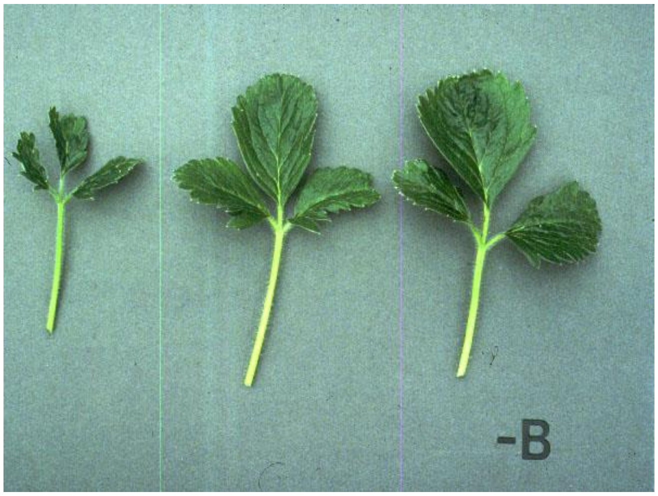
Zinc deficiency. Zn deficiency is common in tree fruit crops, particularly on sandy soils. Also known as "little leaf disease" as leaves tend to be smaller in size; internodes are shorter. Young leaves will appear yellowed and folded upward along the midribs. Zn deficiency is also characterized by interveinal yellowing similar to that of Fe deficiency. Zn deficiencies often occur when P is present in excess. (*Figure 16c*)

Figure 16c. *Zinc deficiency in a strawberry plant. Photo courtesy: Industry and Investment NSW.*

Boron deficiency. This is often a deficiency we see in NE soils. Often one we suggest to test for. Dieback in blueberries is similar to winter injury (*Figure 17a*). Why dieback? Boron is responsible for auxin production, stimulating root growth and elongation (*Figures 17b, 17c*). Thus root systems are compromised, other micronutrients also deficient. Another symptom in strawberry is asymmetrical leaflet growth (*Figure 17d*). Boron deficiency also may cause deformed fruits in strawberries; achenes excrete auxin; this process is boron limited (*Figure 17e*). Similar symptoms may also be caused by frost damage and/or tarnished plant bug feeding.

Figure 17a. *Boron deficiency symptoms in Maine blueberry field. Photo courtesy M. Pritts.*

Figures 17b, c, d, e. *Strawberry roots in complete medium with Boron (top left) and without boron (top right) +B, -B, strawberry asymmetrical leaflets, strawberry deformed fruit. Bottom left: strawberry leaves showing signs of boron deficiency; bottom right: strawberry fruits showing the same. Photos courtesy M. Pritts.*



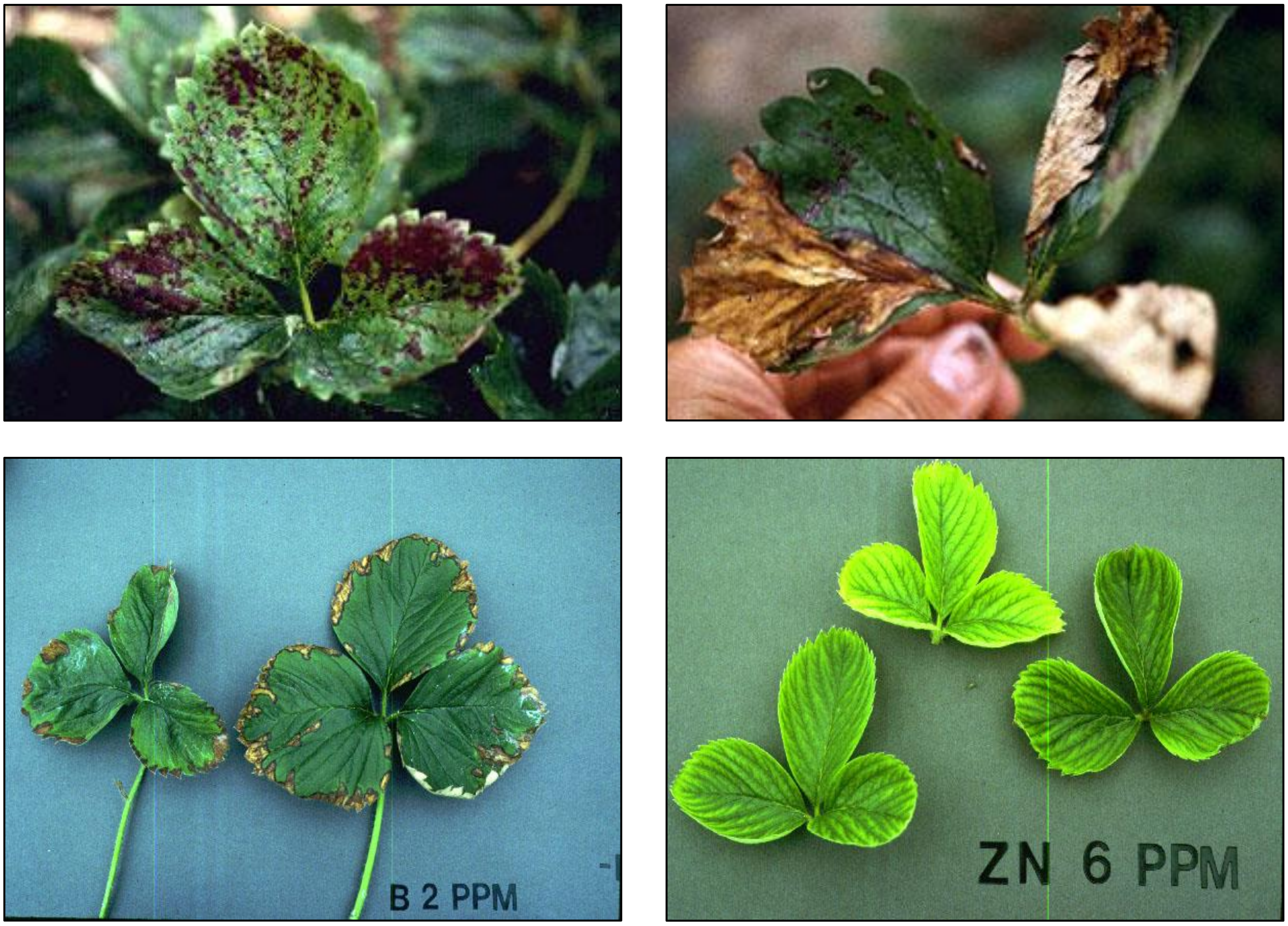
Don’t be fooled!

Herbicide toxicity symptoms often resemble nutrient deficiency symptoms (*Figures 18 a, b, c, d, f*). When symptoms occur, ask questions regarding history of herbicide applications in the planting. Note herbicide injury usually occurs in a regular pattern in the field (ends of rows, every third row where spray might overlap, near wet areas where tractors spin and too much herbicide deposited, etc.) Herbicide injury also usually has rapid onset. Nutrient deficiencies usually develop more slowly over time and often follow the soil type. Similar symptoms may have biological causes such as the mycoplasma that causes June Yellows (*Figure 18e*)

Figures 18a, b, c, d, e, f. *Roundup injury (top left), simazine injury (top right), Sinbar injury (center left), Solicam injury center right, June yellows (bottom left), Solicam injury (bottom right).*

It is important to recognize that over-fertilization can result in injury symptoms that may be confused with deficiency symptoms (*Figures 19a, b, c, d*).

Figures 19a, b, c, d. *Top left and right: Strawberries burned by application of too much ammonium nitrate (excess N); center left: excessive B, center right: too much Zn.*



Summary

A foliar elemental analysis is the best technology we have for assessing plant nutrient status; foliar test results need to be evaluated in conjunction with a soil analysis for accuracy of interpretation. One should try to address nutritional problems before visual symptoms occur. Visual symptoms of nutrient deficiencies are difficult to diagnose and can be confused with other causes.

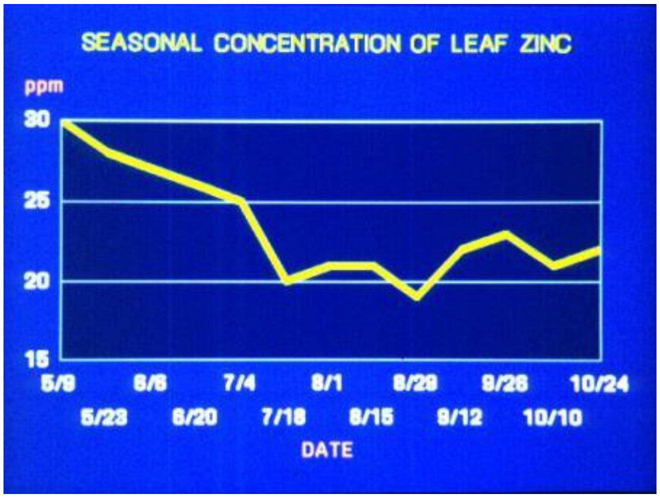
Additional Resources

1. Pritts, M. and Heidenreich, C. 2012. *Cornell Berry Diagnostic Tool*. Available on line at: http://www.fruit.cornell.edu/berrytool/.
2. Wallace, T. 1943. *The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms*. Published by His Majesty's Stationary Office. Available on line at: http://customers.hbci.com/~wenonah/min-def/.
3. Domoto, P. 2011. *Recognizing and correcting nutrient deficiencies in strawberries*. Iowa State University Extension. Available on line at: http://www.iowaproduce.org/pages/fruit/files/strawberry/Strawberry_nutrition_guide.pdf

Chapter 6 Interpreting Foliar Analysis Results - *Dr. Marvin Pritts, Cornell University*

Let's review

When to sample leaves? The best time varies slightly for each crop but in general late July to early August when nutrient levels in leaves are relatively stable is the best time for sampling (*Figures 20a, b*). Seasonal levels of boron and zinc, for example, start out relatively high in the spring, drop over the course of the season, then stabilize later in the season when fruit is no longer present.



Figures 20a. *Seasonal concentration of leaf boron, and 20b, leaf zinc.* (*From:* May, G. M., M. P. Pritts and M. J. Kelly. 1994. Seasonal patterns of growth and tissue nutrient content in strawberries. Jour. Plant Nutrition 17:149-1162.)

Strawberry leaves for analysis should be collected from the first regrowth after renovation, selecting the youngest full-sized leaves (July). Blueberry leaf samples should be collected just before or during harvest, choosing leaves from middle of this year's shoots, full sun (July-Aug). For either summer or fall raspberries collect leaves from the primocanes selecting the youngest full-sized leaves (early Aug).

Standard foliar nutrient ranges

There are standard foliar nutrient ranges for all the berry crops; these are generally accepted across the board regardless of location, climates, soils, etc. which make them easier to interpret (*Table 19a*). Note N, P, K, Ca, and Mg values in the table are percentages; B, Mn, Fe, Cu, and Zn values are listed in parts per million (ppm).

Table 19a. *Standard foliar nutrient ranges for strawberries, raspberries and blueberries*

	Strawberries		Raspberries		Blueberries	
Foliar Nutrient	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**
Nitrogen (N)	1.9 %	2.0 - 2.8 %	1.9 %	2.0 - 2.8%	1.7 %	1.7 - 2.1%
Phosphorus (P)	0.2	0.25 - 0.4	0.2	0.25 - 0.4	0.08	0.1 - 0.4
Potassium (K)	1.3	1.5 - 2.5	1.3	1.5 - 2.5	0.35	0.4 - 0.65
Calcium (Ca)	0.5	0.7 -1.7	0.5	0.6 - 2.0	0.13	0.3 - 0.8
Magnesium (Mg)	0.25	0.3 - 0.5	0.25	0.6 - 0.9	0.1	0.15 - 0.3
Boron (B)	23 ppm	30 -70 ppm	23 ppm	30 - 70 ppm	20 ppm	30 - 70 ppm
Manganese (Mn)	35	50 - 200	35	50 - 200	25	50 - 350
Iron (Fe)	40	60 - 250	40	60 - 250	60	60 - 200
Copper (Cu)	3	6 - 20	3	6 - 20	5	5 - 20
Zinc (Zn)	10	20 - 50	10	20 - 50	8	8 - 30

Notice when comparing strawberries and raspberries, both rosaceous plants, the accepted values are relatively the same for both; there's very little different between the two. They grow in similar ways, accumulating nutrients to similar amounts, and these are indicative of healthy plants that are growing normally.

Critical values for blueberries however, are usually quite a bit lower than they are for strawberries and raspberries (Table 19b). One of the things to keep in mind when using a soil and/or leaf testing lab that is not familiar with blueberries, is that they will often use a standard appropriate for strawberries and raspberries (and truthfully for many other crops with similar ranges, such as alfalfa) on which to base their recommendations. They need to be adjusted down quite a bit for blueberries. Blueberries have a lower nutrient requirement than other crops, they grow more slowly, they don't require much nutrient, and critical levels in leaves are much lower in most cases. Keep that in mind if you get nutrient recommendations that don't seem right, it may be that the lab is using the wrong standard, one that has not been adjusted for blueberries.

Table 19b. *Standard foliar nutrient ranges for strawberries and raspberries vs. blueberries*

	Strawberries		Raspberries		Blueberries	
Foliar Nutrient	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**
Nitrogen (N)	1.9 %	2.0 - 2.8 %	1.9 %	2.0 - 2.8%	1.7 %	1.7 - 2.1%
Phosphorus (P)	0.2	0.25 - 0.4	0.2	0.25 - 0.4	0.08	0.1 - 0.4
Potassium (K)	1.3	1.5 - 2.5	1.3	1.5 - 2.5	0.35	0.4 - 0.65
Calcium (Ca)	0.5	0.7 -1.7	0.5	0.6 - 2.0	0.13	0.3 - 0.8
Magnesium (Mg)	0.25	0.3 - 0.5	0.25	0.6 - 0.9	0.1	0.15 - 0.3
Boron (B)	23 ppm	30 -70 ppm	23 ppm	30 - 70 ppm	20 ppm	30 - 70 ppm
Manganese (Mn)	35	50 - 200	35	50 - 200	25	50 - 350
Iron (Fe)	40	60 - 250	40	60 - 250	60	60 - 200
Copper (Cu)	3	6 - 20	3	6 - 20	5	5 - 20
Zinc (Zn)	10	20 - 50	10	20 - 50	8	8 - 30

There is one exception for blueberries - manganese (Table 19c). It won't have much impact on your interpretation except you might see high manganese values in blueberries occasionally. For other crops this might signal a toxicity problem, but not blueberries. Blueberries have evolved a tolerance to high Mn levels. At low pH levels, manganese levels tend to be higher. The other thing is blueberries have evolved in flooded soils. These soils have less oxygen. Oxygen diffuses 1,000 – 10,000 times more rapidly in aerated vs. waterlogged soils. When oxygen isn't available as an electron acceptor for respiration (as it normally would be without flooding), other elements are used instead. The next thing an electron goes to after oxygen is manganese. Mn++++ (IV), the form typically found in soil, then converts to Mn++(II) form, the biologically active form. Mn++ is rapidly taken up by the plant. Blueberries take this form and isolate it in vacuoles so that does not become toxic. This is not a problem unless levels become extremely high in the plant.

Table 19c. *Manganese nutrient ranges for strawberries and raspberries vs. blueberries*

	Strawberries		Raspberries		Blueberries	
Foliar Nutrient	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**	**Critical Value**	**Normal Range**
Nitrogen (N)	1.9 %	2.0 - 2.8 %	1.9 %	2.0 - 2.8%	1.7 %	1.7 - 2.1%
Phosphorus (P)	0.2	0.25 - 0.4	0.2	0.25 - 0.4	0.08	0.1 - 0.4
Potassium (K)	1.3	1.5 - 2.5	1.3	1.5 - 2.5	0.35	0.4 - 0.65
Calcium (Ca)	0.5	0.7 -1.7	0.5	0.6 - 2.0	0.13	0.3 - 0.8
Magnesium (Mg)	0.25	0.3 - 0.5	0.25	0.6 - 0.9	0.1	0.15 - 0.3
Boron (B)	23 ppm	30 -70 ppm	23 ppm	30 - 70 ppm	20 ppm	30 - 70 ppm
Manganese (Mn)	35	50 - 200	35	50 - 200	25	50 - 350
Iron (Fe)	40	60 - 250	40	60 - 250	60	60 - 200
Copper (Cu)	3	6 - 20	3	6 - 20	5	5 - 20
Zinc (Zn)	10	20 - 50	10	20 - 50	8	8 - 30

Deficient or not deficient?

Foliar analysis will give you values for nutrients that are not commonly reported in soil tests such as Manganese, Iron, Copper and Zinc. The probability of any one (or more) nutrients being deficient varies across nutrients (Table 20).

Table 20. *Probability of a nutrient deficiency occurring in leaves*

Nutrient	Probability of being deficient
Nitrogen (N)	Low – often in excess
Phosphorus (P)	Low
Potassium (K)	Medium – lighter soils
Calcium (Ca)	Low – except on acid soils
Magnesium (Mg)	Medium – higher for blueberries
Manganese (Mn)	Medium
Iron (Fe)	Low – higher for blueberries
Boron (B)	Medium High (Atlantic coastal plain)
Zinc (Zn)	Medium (high P soils)
Copper (Cu)	Low (high OM soils)

Nitrogen is in leaves is rarely reported as low. Most growers fertilize fairly well with nitrogen. In fact it is often reported above the critical values as growers tend to put on more than they really need. In this instance leaf analysis values will be reported as high (to excessive).

Phosphorus. The same is true for P as for N; reported leaf levels rarely come back as low. Phosphorus levels are generally relatively high due to nature of soils in NE region, the past presence of dairy farms on production fields and/or use of manure to fertilize fields in the past.

Potassium is sometimes low on lighter soils.

Calcium is sometimes low, but a calcium deficiency occurs infrequently, especially if pH is in the appropriate range.

Magnesium sometimes shows up as deficient, particularly in blueberry fields.

Manganese shows up as deficient somewhat frequently, particularly in fields that were once wet and have been drained.

Iron in leaves is sometimes low. Iron is a very common element in soils. If iron is reported to be deficient in leaves it is most likely a problem with pH, not a soil deficit. In that instance, pH adjustment often solves the deficiency problem without the need for supplemental application of iron. A chelated iron product is sometimes applied to *foliage* as a temporary measure until soil pH has time to moderate. This is especially true in the case of blueberries.

Boron is an element frequently low in NE region soils. Atlantic coastal plains soils characteristically tend to be very low in boron; parts of Ontario and Canada are also deficient. Boron is the element most commonly found to be reported deficient in leaf analyses.

Zinc. If phosphorus levels are high, then zinc is sometimes low.

Copper – Frequently deficient in soils with high organic matter.

Aluminum (Al). Aluminum levels are routinely determined as part of a standard leaf analysis but are not reported unless specifically requested. Aluminum levels tend to be very sporadic in soils. High aluminum soils with low pH may result in aluminum toxicity; if pH is in the normal range, no evidence of toxicity is apparent. Thus Al toxicity is sometimes seen in blueberries on low pH high Al soils. Raspberries or other crops grown on the same high Al soil at higher pH show no evidence of toxicity…

Foliar test interpretation

Foliar tests are useful for adjusting your fertility program only when plants are healthy and pH is within range. A foliar test doesn't really provide insights if plants are diseased or plants aren't growing well. It's a really good way to fine tune a fertility program but not really meant to be used it as a sole guide for wholesale adjustments.

Leaf analysis interpretation checklist

1. Ensure that the soil pH is within the correct range; if yes, proceed. ***If no, STOP!***
2. Are there any other limiting factors? Assess the status of the planting to determine if something other than nutrients could be limiting growth (disease, drought).
3. Check the status of boron. Low boron may result in deficits in other nutrients…
4. Look for specific nutrients that might be deficient.
5. Check for interactions/imbalances that can exacerbate low nutrient levels.
6. Derive recommendations.

Possible Scenarios

There are three possible scenarios that are seen when examining corresponding soil and leaf tests. They include:

- Leaf test and soil test tell the same story
- Soil test is low for a nutrient, yet leaf test is normal
- Soil test is high for a nutrient, yet leaf test is low

Interpreting Leaf Test Results – Test Your Skills

Eighteen examples follow illustrating the 3 scenarios that may occur. These are taken from paired sets of actual soil and leaf analysis test results and are summarized here for ease of review.

Things to think about when reviewing soil and leaf test results:

- ✓ Optimal pH ranges for each crop:
  - Strawberries and raspberries: 6.2 – 6.5
  - Blueberries: 4.2 – 4.8
- ✓ Desired organic matter content: greater than 2%
- ✓ Optimal soil Boron level: 1.0 lb/A or above
- ✓ Standard foliar nutrient ranges for strawberries, raspberries, and blueberries. Remember N, P, K, Ca, and Mg values in the table are percentages; B, Mn, Fe, Cu, and Zn values are listed in parts per million (ppm).
- ✓ Plants compromised by disease do not grow very much. Unhealthy plants often have normal to high soil and leaf nutrient levels; you need to look at plant health as well as test results to determine what is else is happening…
- ✓ Do your soil test recommendations change once you have data on foliar analysis?

Example# 1: Strawberries, Castile soil, Good growth and yield

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Normal
Potassium (K)	High	Normal
Calcium (Ca)	High	Normal
Magnesium (Mg)	High	Normal
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)	2.0	Normal
Zinc (Zn)		Normal
pH	6.2	-----
Organic Matter	5.3%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

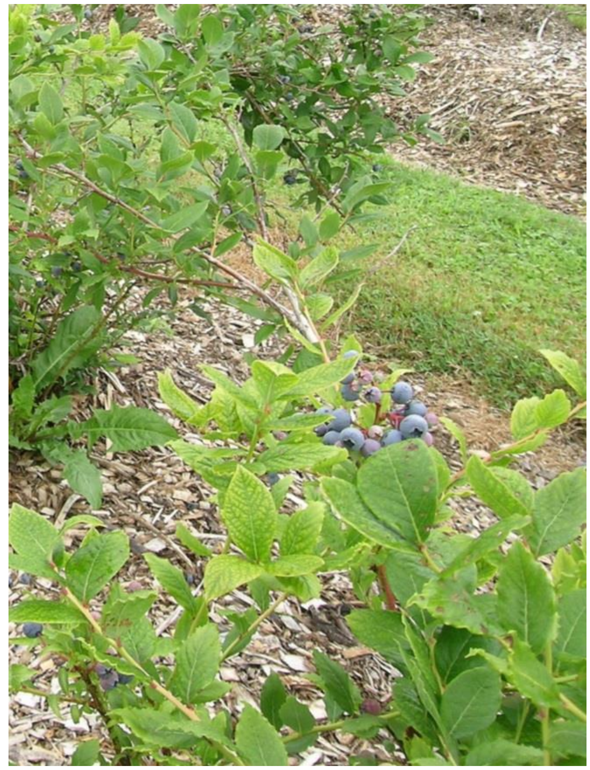
Your Recommendation(s):____

____

Checklist: Soil test results look good; pH is in range, organic matter is good, nutrient levels for soil and leaf tests are normal. **Recommendation:** You're doing the right thing; keep up the good work.

Example# 2: Blueberries, Volusia soil

Nutrient	Leaf (%, ppm)
Nitrogen (N)	Normal
Phosphorus (P)	Normal
Potassium (K)	Normal
Calcium (Ca)	High
Magnesium (Mg)	Normal
Manganese (Mn)	Low
Iron (Fe)	Low
Copper (Cu)	Low
Boron (B)	Normal
Zinc (Zn)	Low
pH	-----
Organic Matter	-----



Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)______________________________________

Your Recommendation(s):____

____

Checklist: Let's start with leaf analysis - Normal N, P, K, Mg, and B levels. High Ca levels; low Mn, Fe, Cu, Zinc.

Recommendation: Check soil pH.

Example#3: Blueberries, Volusia soil

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Normal
Potassium (K)	High	Normal
Calcium (Ca)	High	High
Magnesium (Mg)	High	Normal
Manganese (Mn)		Low
Iron (Fe)		Low
Copper (Cu)		Low
Boron (B)	Medium	Normal
Zinc (Zn)		Low
pH	5.8	-----
Organic Matter	5.3%	-----

High pH means low iron availability. Note iron deficiency symptoms.

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)_______________________________________
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)_______________________________________

Your Recommendation(s):____

____

Checklist: Soil analysis shows that the pH is high at 5.8; the desired range for blueberries is 4.2 to 4.5.
Recommendation: When the last four leaf micronutrients (Fe, Cu, B, Zn) in particular are low together most often it's not an indication that they are low in soil BUT that pH is not where it should be…Adjust pH; no need to amend with micronutrients at this point; once pH has been moderated the levels should return to normal without adjustment.

Example# 4: Strawberries, Tioga (river bottom) soil

Nutrient	Leaf (%, ppm)
Nitrogen (N)	Normal
Phosphorus (P)	Normal
Potassium (K)	Medium
Calcium (Ca)	Low
Magnesium (Mg)	Low
Manganese (Mn)	Normal
Iron (Fe)	Normal
Copper (Cu)	Normal
Boron (B)	Normal
Zinc (Zn)	Medium
pH	-----
Organic Matter	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: Leaf analysis - Normal N, P, K, Mn, Fe, Cu, Zn and B levels. Low Mg and Ca levels. **Recommendation:** Add Mg and Ca.

Example# 5: Strawberries, Tioga (river bottom) soil

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	High	Normal
Potassium (K)	High	Medium
Calcium (Ca)	Low	Low
Magnesium (Mg)	Medium	Low
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)	Medium	Normal
Zinc (Zn)		Medium
pH	5.6	-----
Organic Matter	2.4%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)_____________________________________
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)_____________________________________

Your Recommendation(s):____

____

Checklist: Soil analysis indicates Ca is low, Mg is medium, all other nutrients within normal range; pH is low at 5.6; the desired range for strawberries is 6.2 to 6.5. Leaf analysis also indicates Ca is low, along with Mg.

Recommendation: Adjust pH using high magnesium lime to adjust pH and provide Ca and Mg.

Example# 6: Blueberries, Volusia soil

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Low
Phosphorus (P)	Medium	Normal
Potassium (K)	High	Normal
Calcium (Ca)	High	Normal
Magnesium (Mg)	Medium	Normal
Manganese (Mn)		Normal
Iron (Fe)		Low
Copper (Cu)		Low
Boron (B)	Medium	Normal
Zinc (Zn)		Low
pH	5.2	-----
Organic Matter	5.3%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

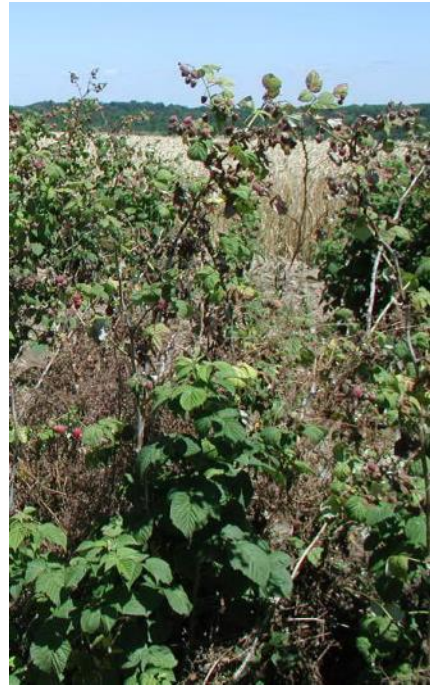
Your Recommendation(s):____

____

Checklist: pH is slightly high at 5.2; organic matter is good; soil nutrient levels all OK. Leaf analysis shows low N, Fe, Cu, Zn. Other leaf nutrient levels are normal. What may be causing nitrogen deficiency? Most likely the weed competition (*photo right*) vs. grower not fertilizing with N fertilizer...**Recommendation:** Manage weeds better; keep N fertilization program the same for now. Adjust pH slightly using sulfur; micronutrients should balance out when pH is in desired range.

Example# 7: Raspberries, Conesus soil, poor growth

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Low	Normal
Potassium (K)	Low	Normal
Calcium (Ca)	Medium	Normal
Magnesium (Mg)	Medium	Normal
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)		Normal
Zinc (Zn)		Normal
pH	6.2	-----
Organic Matter	5.9%	-----



Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: A few soil things are low here (P and K); Ca, Mg are medium, pH is OK, organic matter is good. Leaf levels are all normal but plants are not growing well. **Recommendation:** The problem probably isn't nutritional as both soil and leaf nutrient levels are good. Look for another factor affecting growth.

Example# 8: Strawberries, Bath soil, plants not healthy

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	High	Normal
Potassium (K)	High	Normal
Calcium (Ca)	High	Normal
Magnesium (Mg)		Normal
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)	1.0	Normal
Zinc (Zn)		Normal
pH	6.4	-----
Organic Matter	3.8%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: pH and organic matter good, soil and leaf nutrient levels all OK but plants not healthy. What's happening here? **Recommendation:** The problem probably isn't nutritional. Look for another factor affecting growth such as black root rot, strawberry root weevil etc.

Example# 9: Strawberries, Castile soil (soil test only)

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	Medium
Calcium (Ca)	High
Magnesium (Mg)	High
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	0.9
Zinc (Zn)	
pH	5.8
Organic Matter	4.4%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____

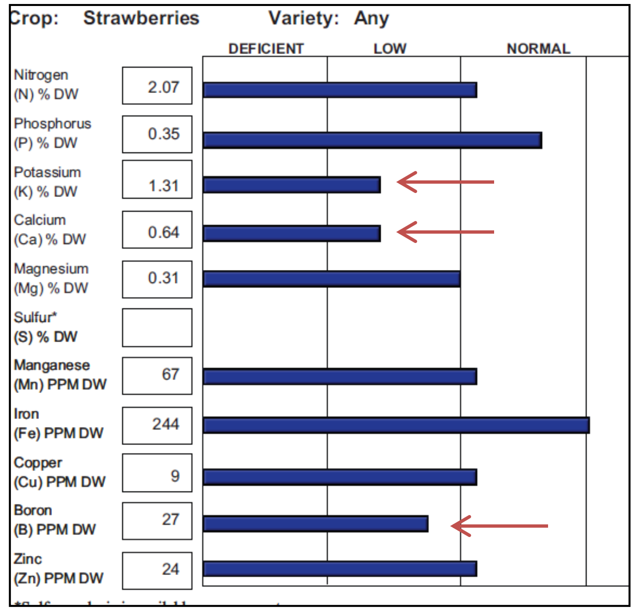
Your Recommendation(s):____

____

Checklist: pH is low; optimal range for strawberries 6.2 to 6.5, organic matter OK, nutrient levels OK except Boron. **Recommendation:** Raise pH; add boron.

Example# 10: Strawberries, Castile soil (with foliar analysis)

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Normal
Potassium (K)	Medium	Low
Calcium (Ca)	High	Low
Magnesium (Mg)	High	Normal
Manganese (Mn)		Normal
Iron (Fe)		High
Copper (Cu)		Normal
Boron (B)	0.9	Low
Zinc (Zn)		Normal
pH	5.8	---------
Organic Matter	4.4%	---------



Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: Leaf analysis shows K and Ca are low; Boron is low. **Recommendation:** Raise pH (and Ca level at the same time) using 2 T/A lime (per soil test recommendation), add 90 lbs K/A and 4 lbs Solubor (per leaf test recommendations).

Example# 11: Strawberries planted 2010, well-drained soil, dry year (soil test only)

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	High
Potassium (K)	High
Calcium (Ca)	High
Magnesium (Mg)	High
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	0.7
Zinc (Zn)	
pH	6.2
Organic Matter	3.9%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

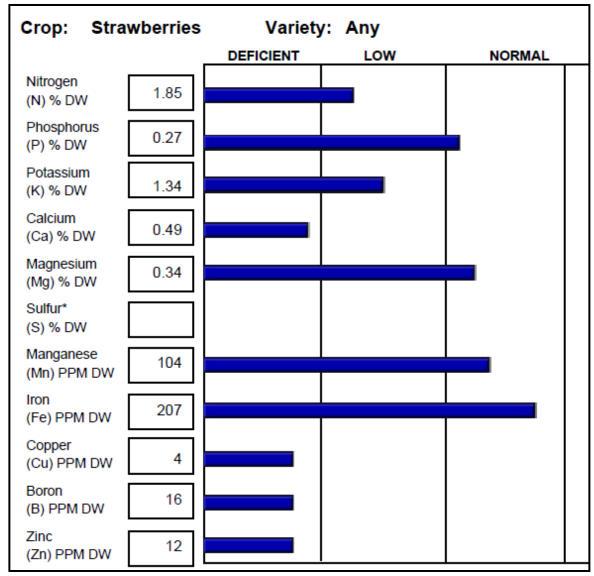
____

Checklist: pH and Organic matter OK; P, K, Ca, Mg high; Boron low, desired range 1.0 lb/A or higher.

Recommendation: Raise Boron level.

Example# 12: Strawberries planted 2010, well-drained soil, dry year

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Low
Phosphorus (P)	High	Normal
Potassium (K)	High	Low
Calcium (Ca)	High	Low
Magnesium (Mg)	High	Normal
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Low
Boron (B)	0.7	Low
Zinc (Zn)		Low
pH	6.2	---------
Organic Matter	3.9%	---------



Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____________________________________
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____________________________
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____________________________
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)_________________________
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)_________________________

Your Recommendation(s):____

____

Checklist: N, P, Ca high for soil analysis but low for leaf analysis; Cu, B, Zn also low for leaf analysis.
Recommendation: Drought likely limiting uptake of Ca and K. Irrigate. Don't need complete fertilizer as soil levels of P and K are fine. Fall fertilize with urea (30 lbs actual N/A, ~60 lbs urea) and boron (5 lbs/A solubor).

Example#13: Summer Raspberries Conesus soil, very heavy crop load

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	Medium
Potassium (K)	High
Calcium (Ca)	High
Magnesium (Mg)	High
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	1.2
Zinc (Zn)	
pH	6.2
Organic Matter	4.9%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)______________________________________

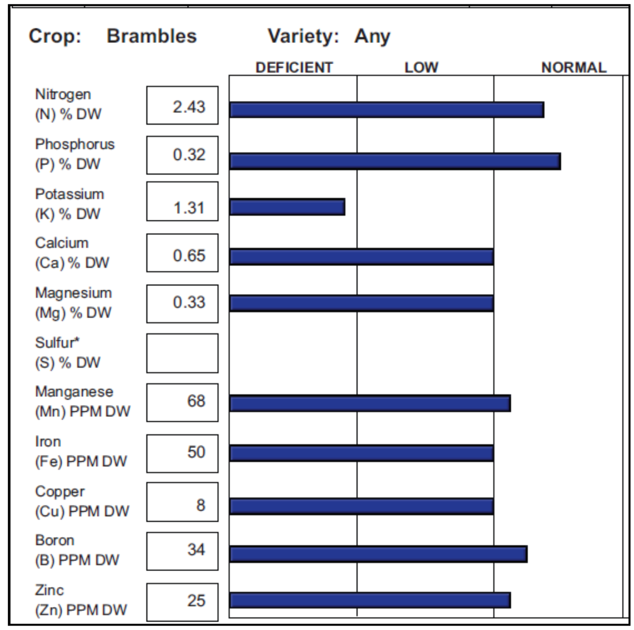
Your Recommendation(s):____

____

Checklist: pH and Organic matter fine; soil nutrient levels also good. **Recommendation:** Nothing needed; keep up the good work…

Example# 14: Raspberries Conesus soil, heavy crop load

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Normal
Potassium (K)	High	Low
Calcium (Ca)	High	Normal
Magnesium (Mg)	High	Normal
Manganese (Mn)		Normal
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)	1.2	Normal
Zinc (Zn)		Normal
pH	6.2	---------
Organic Matter	4.9%	---------



Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: Everything good except potassium (K) is low. Why? Soil levels are high… **Recommendation:** Fruiting takes a lot of K; just need to allow time for plants to replenish from soil irrigate to maintain soil moisture so this can happen.

Example# 15: Strawberries, poor growth

Nutrient	Soil (lb/A)
Nitrogen (N)	---------
Phosphorus (P)	High
Potassium (K)	High
Calcium (Ca)	High
Magnesium (Mg)	Medium
Manganese (Mn)	
Iron (Fe)	
Copper (Cu)	
Boron (B)	2.0
Zinc (Zn)	
pH	6.5
Organic Matter	3.4%

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: pH and Organic matter OK; other nutrient levels OK, Boron OK. **Recommendation:** Look for another cause of poor growth such as a disease or drought.

Example# 16: Strawberries, poor growth

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Very High	High
Potassium (K)	High	High
Calcium (Ca)	High	High
Magnesium (Mg)	Medium	Low
Manganese (Mn)		Normal
Iron (Fe)		Low
Copper (Cu)		Low
Boron (B)	2.0	Normal
Zinc (Zn)		Low
pH	6.5	---------
Organic Matter	3.4%	---------

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____________________________________
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____________________________________
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)__________________________________
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)__________________________________

Your Recommendation(s):____

____

Checklist: pH and organic matter OK. Mg medium for soil analysis but low for leaf analysis; Fe, Cu, Zn also low for leaf analysis. **Recommendation:** Sometimes soil nutrient can be too high; P is high (too much manure or P fertilizer. P interacts with many micronutrients, forming precipitants and tying them up. Likely this is what's happening here. High Ca can also interfere with iron; this is particularly true for blueberries; not uptake, but the fact it becomes the inactive form and becomes unavailable. If soil P is exceptionally high, you may want to select another site before planting berries.

Example# 17: Blueberries, poor growth, no disease

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Medium
Potassium (K)	High	High
Calcium (Ca)	High	High
Magnesium (Mg)	Medium	Low
Manganese (Mn)		High
Iron (Fe)		Low
Copper (Cu)		Low
Boron (B)	Medium	Normal
Zinc (Zn)		High
pH	4.5	-----
Organic Matter	3.4%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

____

Checklist: pH and organic matter are good; Mg low; leaves showing typical deficiency symptoms. Why?
Recommendation: Ca, P, Zn, and Mn to some extent compete for binding sites with Mg. High levels of these nutrients are likely suppressing Mg. Apply 100 lb/A Mg.

Example# 18: Blueberries, very poor growth, no disease

Nutrient	Soil (lb/A)	Leaf (%, ppm)
Nitrogen (N)	---------	Normal
Phosphorus (P)	Medium	Normal
Potassium (K)	High	High
Calcium (Ca)	Medium	Normal
Magnesium (Mg)	Medium	Normal
Manganese (Mn)		High
Iron (Fe)		Normal
Copper (Cu)		Normal
Boron (B)	2.0	Normal
Zinc (Zn)		High
pH	4.1	-----
Organic Matter	3.4%	-----

Your checklist:

- ✓ **pH**:____
- ✓ **Organic Matter**:____
- ✓ *Soil Macronutrients* (P, K, Ca, Mg):____
- ✓ *Leaf Macronutrients* (P, K, Ca, Mg):____
- ✓ *Soil Micronutrients*: (Mn, Fe, Cu, B, Zn)____
- ✓ *Leaf Micronutrients*: (Mn, Fe, Cu, B, Zn)____

Your Recommendation(s):____

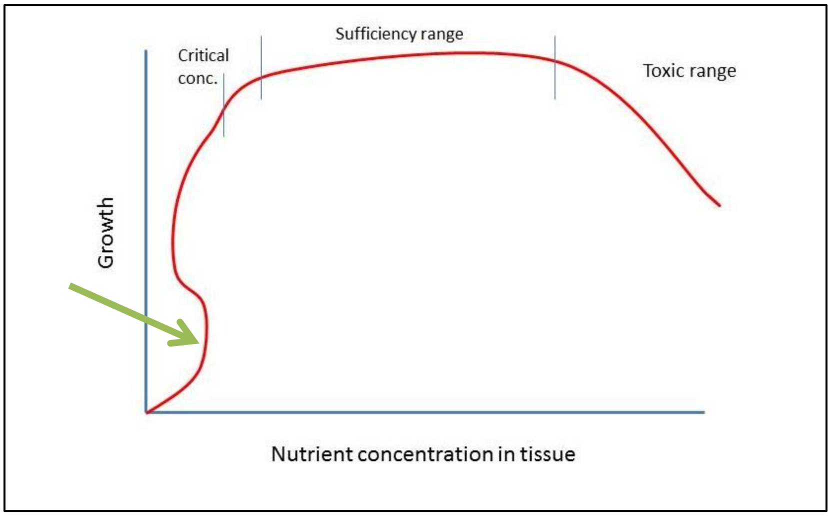
____

Checklist: pH, organic matter, Boron are all good; other soil nutrient levels good; leaf nutrient levels also good. Why poor growth, what's going on? **Recommendation:** There's a possibility of a toxic level of a non-essential element. Check soil test or redo it, asking for all elements to be reported. Look for electrical conductivity/soluble salts. Specifically look at sodium (mid-west, more than east) and aluminum levels. Aluminum is high in many soils and is released at low pH.

The Steenbjerg effect - When adding a fertilizer actually decreases the level of nutrients in a leaf.

This happens when nutrient levels are very low. Think about a situation where the plant has adequate levels of nutrients with the exception of a single nutrient that is very low. Let's select Mg for example. The low level of Mg is limiting growth. Mg is added to the soil and the plant starts to grow rapidly. The concentration of nutrients in the plant may become diluted for a time. This occurs because the plant is now growing faster than it can take up Mg from the soil (Figure 22). After things come to an equilibrium , more normal patterns are expressed. This is why, occasionally, after a recommendation to fertilize, foliar levels decrease the next year, instead of rise.

Figure 22. The Steenbjerg effect



Summary

Soil test results do not always correlate with foliar test results for a variety of reasons. Foliar tests are not meaningful for fertility guidelines unless the soil pH is within the correct range. Foliar tests are useful for diagnosis, but not for detailed guidance unless growth and yield are good. Applying nutrients may result in a decrease in foliar concentrations under certain circumstances, as seen with the Steenbjerg effect. Correcting deficiencies or imbalances in established plantings is more difficult than amending soils prior to planting.

Additional Resources

1. Marschner, H. 1995. Mineral nutrition in higher plants. Academic Press, New York.
2. Plant, cell and environment. 17:1053 – 1060.
3. Wikstrom, F. 1994. A theoretical explanation of the Piper-Steenbjerg effect.

Chapter 7 Correction of Nutrient Problems in Established Berry Plantings - *Dr. Eric Hanson, Michigan State University*

Let's review

Previous chapters have covered soil characteristics, soil testing and interpretation, pre-plant soil treatments, plant tissue analyses and interpretation. This chapter will cover what to do if a nutrient need is known in an established planting. Macro-nutrients include N, P, K, Ca, Mg, and S. Micronutrients include B, Cu, Fe, Mn, Mo, and Zn.

Nitrogen management

Nearly all berry crops require nitrogen on an annual basis. The big question is what you can do to use nitrogen efficiently. Answers to this question include choosing the right fertilizer, fertilizer rate, application timing, and product placement.

Nitrogen fertilizers

There are a lot of nitrogen fertilizers to choose from. Products with the highest nitrogen content tend to be the cheapest per pound of nitrogen and are generally the most preferred N sources. Nitrogen products also vary in their reaction in the soil (Table 21).

Table 21: *Nitrogen fertilizers and their lime equivalents*

Source	%N	Reaction	Lime equivalent (lb lime/lb N)*
Ammonium nitrate	32	acidic	-1.8
Ammonium sulfate	21	acidic	-5.3
Calcium nitrate	16	basic	1.3
Potassium nitrate	12	basic	1.9
Urea	46	acidic	-1.8
Diammonium phosphate (DAP)	17	acidic	-4.1
Monoammonium phosphate (MAP)	11	acidic	-3.5
Blends	variable	variable	variable

**Lb lime equivalent to alkalinity from 1 lb N (positive values) or required to neutralize the acidity from 1 lb N (negative values)*

All those that supply nitrogen in the ammonium (or ammonium plus nitrate) form tend to have an acidifying reaction in soil. Those fertilizers that supply nitrogen only as nitrate have a basic reaction in soil. The measurement of this effect is called the lime equivalent. Essentially the lime equivalent is the lbs of lime that would be equivalent in reaction to 1 lb of nitrogen supplied as a nitrogen fertilizer. For example, if you were to apply 1 lb of N as calcium nitrate it has a positive number indicating for every lb of nitrogen applied as that source it would have the equivalent reaction in soil as 1.3 lb of lime. This is not a large amount of lime but over time could accumulate and affect soil pH. Those with negative numbers would indicate you need to add lime to neutralize the acidity supplied by those sources. Ammonium sulfate is known to be a good N fertilizer for blueberries. The reason for that is that it is so acidifying. For every pound N applied ammonium sulfate as you would need to apply 5 lb of lime to neutralize the acidity.

Choosing nitrogen sources

The choice of nitrogen source should be based first on cost per pound of nitrogen, and then second on the need for other nutrients, particularly phosphate. That would be a reason to choose ammoniated phosphates. Thirdly, one should take into consideration soil pH needs to be changed and in which direction, and then finally, volatilization losses.

For blueberries, preferred nitrogen sources are urea and ammonium sulfate. If your pH is below 5.0 the material of choice would be urea (less acidifying); you might opt for Monoammonium phosphate (MAP) or Diammonium phosphate (DAP) if your P is also low (slightly acidifying). Ammonium sulfate is the product of choice if your soil pH is above 5.0 to further reduce pH. Again you might consider using MAP or DAP if your P is low in this case.

For brambles and strawberries, usually the cheapest forms of nitrogen fertilizer are again best so urea and/or ammonium nitrate are good choices. A number of growers use calcium nitrate; there may be some reasons for that particularly in the middle of the summer when there is concern about volatilization losses.

Volatilization losses of nitrogen

When we talk about this volatilization aspect we are primarily concerned with urea. When you apply urea prills to the soil surface the first thing that happens is hydrolysis (Figure 23a). As it takes up water that small organic molecule hydrolyzes and produces ammonium and bicarbonate. The important aspect to this is that it has the immediate effect of increasing the pH around that prill or in that immediate vicinity. If ammonium is present near the soil surface under high pH conditions it can be converted to ammonia gas and lost to the atmosphere (Figure 23b).

Figure 23a: *The urea volatilization process*

Urea + Water $\longrightarrow$ Ammonium + Bicarbonate

Urea Hydrolisis: $$CO(NH_2)_2 + H^+ + 2H_2O \longrightarrow 2NH_4^+ + HCO_3^- \text{ (pH increase)}$$

Figure 23b: *The urea volatilization process (continued)*

Ammonia Volatilization: $$NH_4^+ \longrightarrow NH_3^- + H^+$$

This is not to say that ammonium that is applied as ammonium sulfate can't volatilize, it can also. But in most cases the pH of the soil is low enough to where volatilization losses are not a big deal.

What increases the potential for volatilization losses of ammonia gas are promoted by 1) Urea particles remaining on the soil surface (not irrigated in immediately, no rainfall), 2) High temperatures (above 80 ^oF) and 3) high soil pH. In the case of blueberries where pH is naturally low there is less likelihood for loosing nitrogen as ammonia gas. It is something to consider however in the case of strawberries when you might be fertilizing in the middle of the summer when temperatures a very hot. The potential then for volatilization is very high. One would need to make accommodations to reduce that potential by irrigating the fertilizer into the soil to protect it.

General nitrogen rates for berry crops

Applying the proper nitrogen rate is important in terms of maximizing the efficiency of nitrogen use by any crop. If one applies more than the crop needs, use efficiency decreases and other problems may ensue from the excess.

Recommended rates vary from state to state and region to region, and certainly with various soil types. Tables 22 a, b, and c give a general range for blueberries, raspberries and blackberries, and strawberries.

Tables 22a, b, c. *General nitrogen rates (lb actual nitrogen/acre) for berry crops (rates may vary by region)*

Table 22a. Blueberries (higher rates on sandier soils low in organic matter)			
Yrs. 1-2	**3-4**	**5-6**	**7 and older**
15-20	20-40	30-60	40-70

Rates for blueberries start out relatively low at 15 – 20 pound actual N per acre for plants 1 to 2 years old and increase over time. As the planting reaches maturity (7 years and older) the rate would be between 40 and 70 lb actual N/A. The sandier the soil, the lower the organic content, the higher the rate of N you might need.

Table 22b. Raspberries and blackberries (higher rates on sandy soils and fall bearing types)		
Yrs. 1	**Yrs. 2**	**Yrs. 3 and older**
20-40	30-60	50-100

For brambles the progression is similar starting with a lower rate of 20 to 40 lb actual N the first year, and up to 30 to 60 lb actual N/A the second year. The third year (and older) the rate would be 50 to 100 lb/A. Again the higher rates would be applied on sandier soils. There is also some indication that fall-bearing raspberries would require higher rates than summer-bearing raspberries. This makes sense as they are cut entirely to the ground each spring and then generate a whole new stand of canes and a producing a fruit crop all in one season. Growers particularly on sandier ground will find that rates even as high as 100 lb actual N/A may be optimizing yield for fall-bearing raspberries.

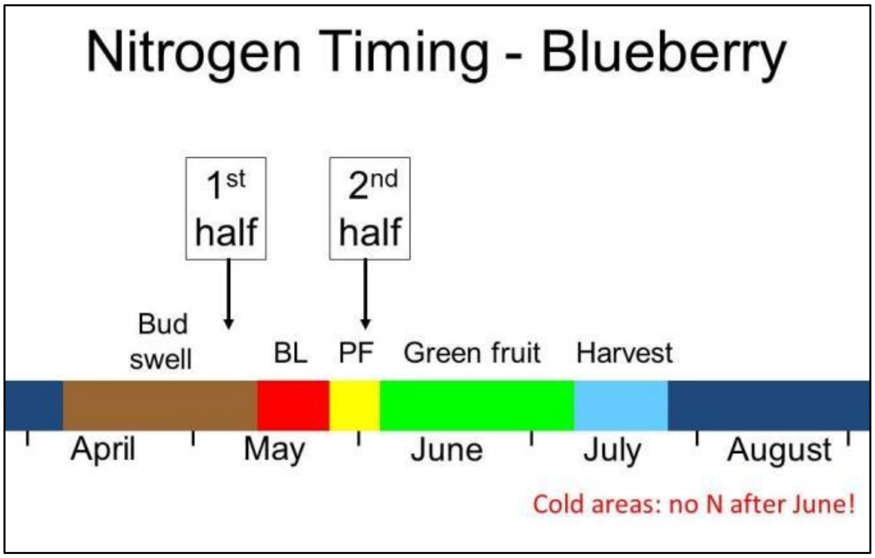
Table 22c. Strawberries (higher rates on sandier soils)	
Yrs. 1	**Yrs. 2 and older**
40-60	50-100

For strawberries the rates vary somewhat from region to region but for the planting year rates of 40 to 60 lb actual N per acre are suggested and then for production years 50 to 100 lb with rates higher on sandier soils.

Nitrogen application timing

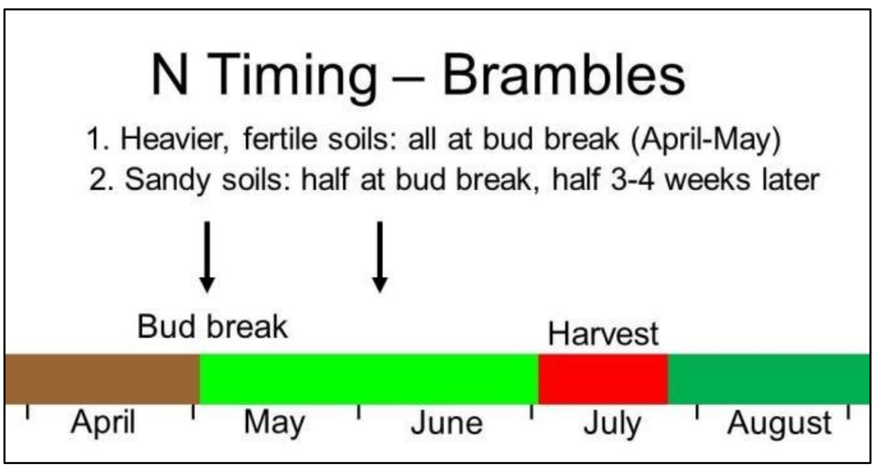
Timing is a critical factor in terms of optimizing nitrogen use (Figures 23a, b, c). A good system for blueberries is to apply N fertilizer in a split application with half of it going on a bud swell time before bloom, and the second half going on during petal fall perhaps 3 weeks later (Figure 24a). This provides nitrogen to the plant early during the rapid growth flush through bloom, petal fall and green fruit. The second application maintains adequate levels through the harvest period. If growing on heavier soils or with higher organic content you may not observe a significant benefit with a split application; one application at bud swell may suffice. The split application system is likelier to be of benefit particularly on sandier sites. If growing blueberries in colder locations where winter injury is a concern then applying nitrogen later than June 30th should be avoided. N applications made later than June in colder growing areas tends to reduce hardiness of the bushes going into winter. If growing hardy blueberries in a less stressful winter location nitrogen may be applied a little bit later in the season. If you are growing blueberries in locations that are stressed by the winter year after year care should be taken in applying nitrogen or maintaining high levels of nitrogen later in the season.

Figure 23a. *Timing of nitrogen applications for blueberries.*



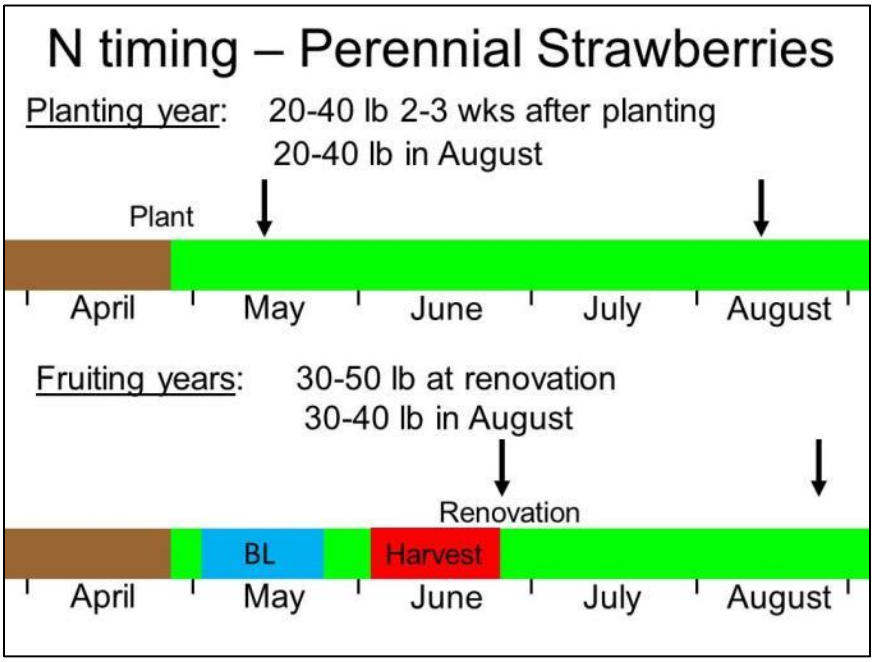
For brambles, the decision on when to apply nitrogen again is somewhat dependent on soil type (Figure 23b). On heavier, fertile soils it is best to apply all of the nitrogen at bud break time in April or May. If growing brambles on sandier soil with low organic matter a split application is recommended with half of the N fertilizer being applied at bud break and the remaining half being applied 3-4 weeks later. This maintains levels of nitrogen available to the plants later into the growing season; this is particularly important for fall-fruiting types to support production into September and October.

Figure 23b. *Timing of nitrogen applications for brambles.*



Recommendations for N application timing vary from planting year to fruiting years for perennial strawberries (Figure 24c). The planting year recommendation is for 20-40 lbs N to be applied 2-3 weeks after planting. This application should be delayed until rain or irrigation has settled the soil around the plants. A second application should be made in August. During the fruiting year the recommendation changes somewhat; 30 to 50 lb nitrogen should be applied at renovation time after harvest, followed by about the same amount again in late August to early September. Some growers producing strawberries on sandy ground feel they need a small amount of nitrogen (10 lb/A or so) in early spring,. This type of application is somewhat risky as it may generate too much vegetation.

Figure 23c. *Timing of nitrogen applications for perennial strawberries.*



Nitrogen placement

The issues in nitrogen placement are a balance between the need to put the fertilizer where it's readily available to the plant vs. not concentrating the fertilizer so much you create salt issue with resulting plant injury. With young plants in the 1st and 2nd years, apply fertilizer by hand in a 2 to 3-ft wide circle around the plant or in a 3 to 4-ft wide band down the row. Broadcasting fertilizer over the entire surface at this point is very inefficient. As the bushes mature, the root systems of these old bushes intertwine in between the rows; any advantage then with banding fertilizer in the row is likely lost and broadcasting fertilizer makes more sense.

Nitrogen placement in brambles again would be similar to that of blueberries. During the planting year it would be applied in a circle around each plant or in a band down each row. In an established planting the situation might also to be to broadcast the fertilizer in a band down the row as most growers are trying to establish a sod row middle along with fertilizing the raspberries.

In perennial strawberries the planting year strategy would be to broadcast the fertilizer in larger because of the close row spacing; it may make some sense to band apply the fertilizer in a smaller planting. Broadcast application would be most suitable for fertilizing established plantings.

Nitrogen release rates from organic nitrogen sources

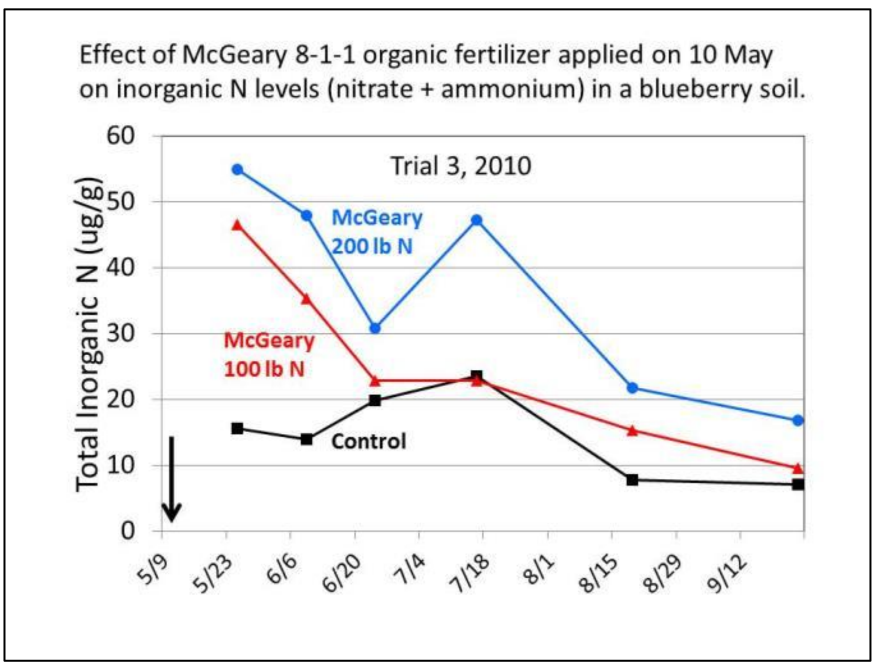
There are a number of organic materials to choose from, of both of plants and animal origin (Table 23). They are relatively high in nitrogen and release a larger percentage of their nitrogen the first year. Composts and aged manures tend to be more stable and release lower percentages of nitrogen during the first year.

Table 23. *Nitrogen content and release rates of some organic sources.*

Material	% N	% available in year 1
Soy meal	7	60-90
Cotton seed meal	6	60-90
Dried blood	12	70-100
Fish meal	14	70-100
Nitrate of soda	16	100
Manure – fresh	0.5 – 2.5	40-80
Manure – dried	2.0 – 5.0	40-80
Compost	0.6 – 2.5	10-40

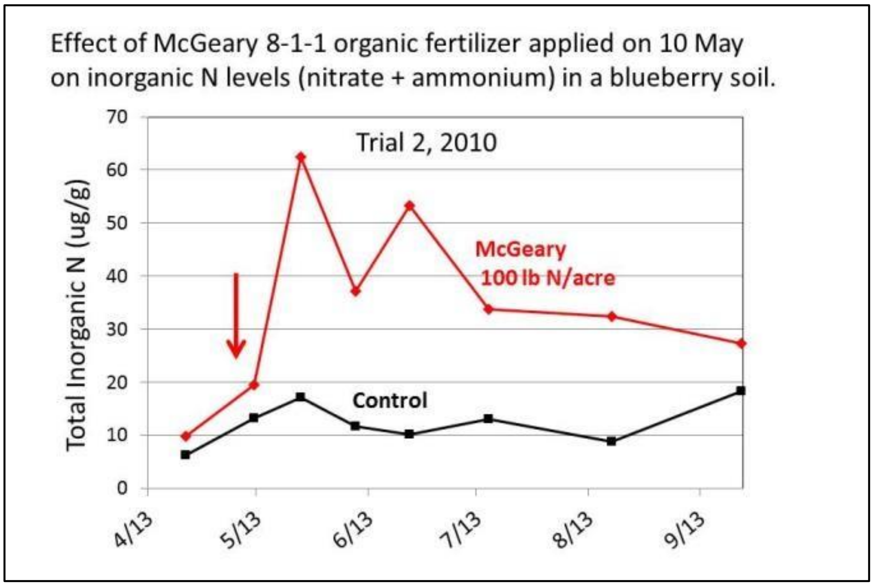
Figure 24 illustrates work done in Michigan with release rates of N from a soy-based organic fertilizer McGeary's 8-1-1 at 2 different rates. The fertilizer was applied on May 10th and total inorganic N (ammonium and nitrate in the soil profile) was monitored. There was an immediate release of available N after application then the release rate tended to decline as the season progressed. Particularly with the higher rate there was still an elevated rate of available N being released into the middle to end of September in this study. This seasonal release on a gradual basis tends to mimic the nitrogen demand needed by the blueberries.

Figure 24. *Release rates of N from a soy-based organic fertilizer, field 1.*



In a study in another field with the same fertilizer (Figure 25); only the lower rate was in this instance. In both of these trials a similar trend was observed with an immediate increase of available nitrogen which declined gradually over the season. And again there was still an elevated rate of available N being released into September. These trials highlight a concern as to how organic blueberries may be fertilized without elevating levels of available nitrogen late in the season when plants should be slowing down and getting ready for winter. A corresponding increase in the levels of bud damage during the winter and winter injury was observed in both trials.

Figure 25. *Release rates of N from a soy-based organic fertilizer, field 2.*



Potassium

Most berry crops have a fairly high demand for potassium; and K needs to be applied perhaps not an annually but often on a somewhat regular basis. Selection of K sources should be made based on whether the production system is conventional or organic, the cost per unit K_2O, the need for other nutrients, and the potential hazard from chloride.

The cost per unit K is cheapest for potassium chloride, potassium sulfate is somewhat higher. The cost for potassium magnesium sulfate. Sul-Po-Mag is even higher per unit K (Table 24). The potential problems with potassium chloride are myriad. It contains chloride which when present in high concentrations are damaging to berry crops. There are organic sources of K including potassium sulfate and Sul-Po-Mag (less processed than conventional sources), and wood ash. Wood ash is very alkaline and not recommended for use in blueberries.

Table 24. *Conventional and organic potassium sources.*

Conventional fertilizers	% K_2O	Comments
Potassium chloride	60-62	Chloride hazard
Potassium sulfate	50-54	Moderate expense
Potassium-magnesium sulfate (Sul-Po-Mag)	22 (11% Mg)	Expensive if Mg is not needed
Organic fertilizers	**% K_2O**	**Comments**
Potassium-magnesium sulfate (Sul-Po-Mag)	18 (11% Mg)	Expensive if Mg is not needed
Potassium sulfate	40-48	Moderate expense
Wood ash	4	Very alkaline

Rates of potassium for existing plantings are those based on soil tests, but generally 100-200 lb K_2O per acre is used to correct most shortages followed by 50-100 lb K_2O per acre for maintenance.

Unlike nitrogen, the timing for potassium is not so critical; it may be applied anytime. That said, fall application is preferred for potassium chloride (muriate of potash) to allow time for chlorine$^-$ to leach out of the root zone before plants begin growing the following spring. This is especially important of you are applying high rates of K. It is important to note excessive K use can cause Mg shortages.

Phosphorus

There are a number of different P materials to choose from; conventional sources are all very highly soluble and highly available to berry crops (Table 25). If you have a need for P then ammoniated phosphates are good choices but if you need only P they are rather expensive. For organic producers bone meal and fish meal are good sources. Rock phosphate isn't used too often as a P source but in the case of blueberries where very acidic soils are present rock phosphate might be a reasonable source as the solubility is quite a bit higher.

Table 25. *Conventional and organic phosphorus sources.*

Conventional fertilizers	% P_2O_5	Availability of P
Superphosphate	21	Very high
Concentrated superphosphate	45	Very high
Di-ammonium phosphate	46	Very high
Mono-ammonium phosphate	52	Very high
Organic sources	**% K_2O**	**Comments**
Bone meal	20-30	moderate
Fish meal	4	moderate
Rock phosphate	3	Very low

Magnesium and Calcium

Sources vary from Epsom salts to various limes (Table 26). Typically, if soils are low in magnesium or calcium it almost always indicates pH is too low. If pH is low, use of dolomitic or calcitic lime is recommended; select one or the other based on soil test results; often dolomitic lime is the material of choice when Mg is low. If pH is appropriate, use gypsum for Ca, or Epsom salts or potassium-magnesium-sulfate for Mg. Apply Ca and/or Mg whenever need is determined.

Table 26. *Calcium and magnesium sources.*

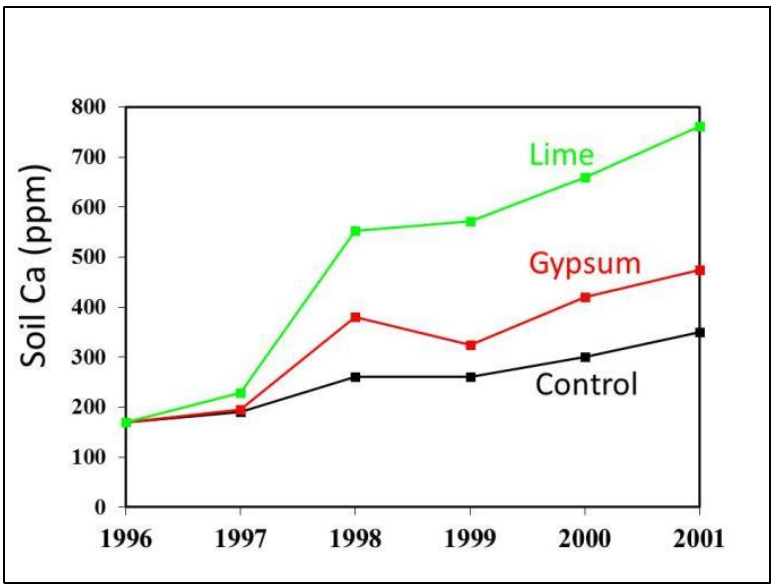
Ca and Mg Sources	% Mg	% Ca	% K
Magnesium sulfate (Epsom salts)	10	--	--
Calcium sulfate (gypsum)	--	22	--
Potassium-magnesium sulfate	11	--	22
Calcitic lime	<5	>30	--
Dolomitic lime	>5	<30	--

Calcium and fruit quality

Elevated levels of calcium in tissue are often associated with improved fruit quality. Research has shown there is a reduced incidence of some physiological disorders in fruit with elevated calcium levels. For example, bitter pit is a localized deficiency of Ca in apple fruit. There is also an increased firmness that accompanies an increase in fruit calcium concentration. Ca inhibits enzymes associated with degradation of cell walls and tissue senescence. There is also a reduction of rot caused several fungal pathogens. This may also be related to Ca inhibiting fungal enzymes that break down tissues.

Calcium also affects berry quality. Increasing levels of Ca in berries can improve the quality of berry fruit. For example, post-harvest Ca fruit dips increased firmness and/or reduced rot in blueberries and strawberries but the commercial utility of this practice is limited due to quality issues in itself. These dips did demonstrate however if there are ways to increase Ca levels in fruit there is some benefit. The most likely approach would be spraying fruit with Ca sprays prior to harvest. Preharvest calcium sprays have been demonstrated in studies to sometimes increase firmness, prolong shelf-life, and/or reduced Botrytis rot…but not always consistently. If Ca sprays are to be used, consider leaving an untreated area in the filed so comparisons may be made to verify effects (or lack thereof…).

Figure 26. *Effect of annual application of lime (1,000 lb) and gypsum (500 lb) on calcium levels in an acidic blueberry soil.*

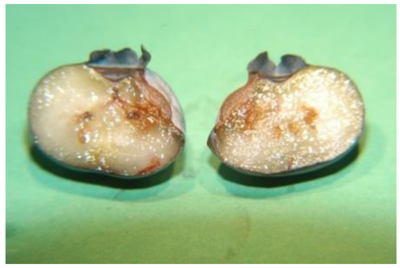


Another way to supply calcium to berry plants is through the roots (Figure 26). For blueberries modest rates of lime and gypsum raised soil pH and Ca, but had inconsistent effects on leaf Ca levels and no effect on fruit Ca. Treatments did not affect fruit yield, shelf life, or firmness.

Boron

Boron is an interesting micronutrient and it can become deficient in berry crops. If there is a boron deficiency it generally causes poor shoot growth and dieback, reduced fruit set or sometimes fruit deformities (Figures 27 a, b, c). Berries are sensitive to excess boron; it is not wise to apply boron unless soil tests indicate a deficiency. Apply proper rates if soil or leaf analyses show a need. Application options include: 1) a foliar spray of 2 lb Solubor (20% B) per acre in June, 2) a soil spray of 3 lb Solubor in spring, or 3) a soil application of 5 lb borax (11% B) in spring.

Figure 27a, b, c. *Blueberry showing Ca deficiency (left); inside view, note corky area (center); and strawberries showing B deficiency, (right).*



Iron

Iron deficiencies only occur in berries periodically but almost always occur where soil pH is too high. The best treatment for this usually is to reduce pH. Foliar sprays of Iron chelate may alleviate some leaf symptoms (Figures 28a, b) but usually do not improve overall plant vigor.

Figure 28a, b. *Blueberry showing iron deficiency symptoms on leaves (left); strawberry leaf symptoms of the same (right).* Photos courtesy E. Hanson and M. Pritts.

Manganese

Manganese deficiencies occur occasionally in berries in the Midwest, and appear to be even less common in the Northeast. The cause is usually a pH that is too high. Blueberries are seldom if ever are deficient in Mn as they are grown on low pH soil where Mn is readily available. To alleviate Mn deficiencies follow these steps. First, check and reduce pH if it is too high. Second, use foliar sprays of manganese sulfate or Mn-chelates to correct shortages if pH is appropriate. And third, Maneb, Dithane, and Manzate fungicides contain about 16% Mn, and can be good sources of manganese for labeled crops such as brambles when used in disease management programs.

Zinc

Zn deficiencies occur occasionally in berries in the Midwest and also the Northeast. Shortages typically occur where soils are sandy and too alkaline (high in pH). Strategies for alleviation of Zn deficiencies are similar to those for manganese: 1) Check and reduce pH if it is too high, 2) Apply foliar sprays of Zn sulfate or Zn chelate products if pH is appropriate and, 3). Ziram fungicide contains about 16% Zn and can be a good source for blueberries and some brambles.

Copper and Molybdenum

Soils in the Midwest and Northeast appear to supply adequate levels of Cu and Mo for berries, as deficiencies in these have not been documented. Copper shortages have occurred in Georgia rabbiteye blueberries. Symptoms include abnormally small leaves and shoot dieback during winter. Fixed copper fungicides (e.g. Kocide, Champ) used in disease management programs are suitable sources of Cu for labeled crops. Note copper salts can potentially injure tissues so use with caution; test the product on a few plants before using widely.

Fertigation

Fertigation is the injection of fertilizers through trickle irrigation systems; this can be a convenient and efficient application method. For berries in the ground, fertigation is most useful for delivering nitrogen and sometimes potassium and phosphorus. The advantages are greater control over nutrient placement and timing and as a result, improved efficiency in terms of reducing the amount of product required, with some caveats. Disadvantages may include cost of investment in equipment and the need for regular maintenance and management (Table 27).

Table 27. *Advantages and disadvantages of fertigation.*

Advantages	Disadvantages
Greater control over nutrient placement and timing	Capital costs: injector, tanks, backflow valve
Improved efficiency; less fertilizer required (if not over-irrigating)	Maintenance (tanks, line plugging) and calibration

Many of these typical fertilizers are very soluble, for example, ammonium nitrate, ammonium sulfate, calcium nitrate. Potassium materials are somewhat lower in solubility than nitrogen materials. Table 28 gives some common products and their solubility in pounds per gallon; note they are extremely high in some cases like ammonium nitrate at 16 lb per gallon. Note values listed in the table are their solubilities at 70 ^{o}F; all product solubilities are lower in cold water.

Table 28. *Solubility of some common fertilizers.*

Fertilizer	Solubility (lb/gal)*
Ammonium nitrate (33-0-0)	16.0
Ammonium sulfate (21-0-0)	6.2
Calcium nitrate (15-0-0)	11.2
Di-ammonium phosphate (21-54-0)	5.7
Mono-ammonium phosphate (11-48-0)	3.1
Urea (45-0-0)	8.8
Potassium chloride (0-0-60)	2.1
Potassium sulfate (0-0-48)	0.9

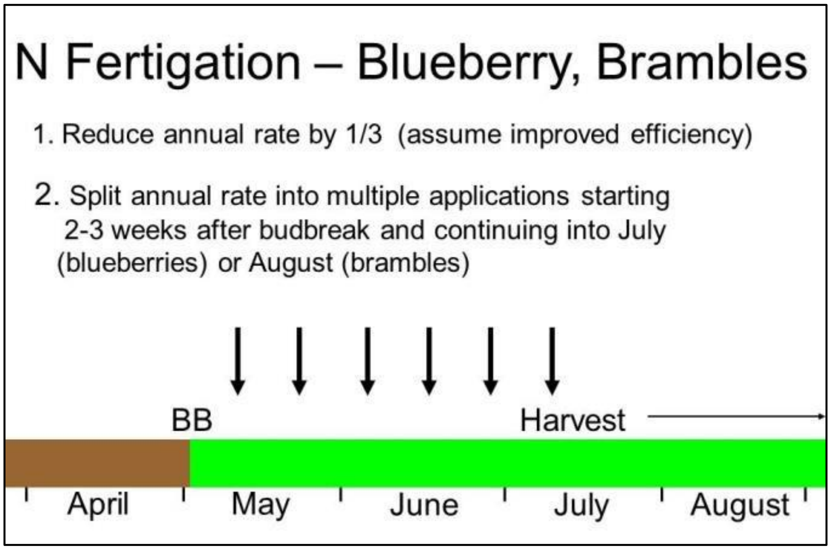
* At 70 ^{o}F. Solubility of all materials is lower in colder water.

Most mixtures may reduce the solubility of some salts. For this reason do not mix calcium with sulfates or phosphates as they may form precipitates causing plugging. Use a “jar test” to test for precipitates.

Nitrogen fertigation for blueberries and brambles

If you are new to fertigation, assume this system will provide improved efficiency and reduce the needed annual nitrogen amount by 1/3rd. Then split the resulting annual rate into multiple applications beginning 2 to 3 weeks after bud break and continuing into July for blueberries and into August for brambles (Figure 29). Fertigation may be done weekly, bi-weekly or every time you irrigate. There may not be much of an improvement seen if one fertigates every time you irrigate versus 3 to 4 times at intervals during the season.

Figure 29. *Nitrogen fertigation for blueberries and brambles.*



Fertigation can be very efficient if the irrigation system has high uniformity, nutrients are applied when demand is high, and plants are not over-irrigated. Over irrigation leaches nutrients below roots making them unavailable. It is very easy to push nitrogen through the profile and down out of reach when pulsing fertilizer through the system and then irrigating heavily afterwards. Figure 30 shows a ditch dug alongside a row of raspberries in a high tunnel with drip irrigation; note water movement into soil.

Figure 30. *Soil profile under raspberry row in high tunnel showing movement of water from fertigation system. (Photo courtesy E. Hanson)*

Chapter 8 Applying the Cornell Soil Health Test to Berry Production- *Robert Schindelbeck, Cornell University*

Introduction

The Cornell soil health test (CSHT) has been available to researchers and the general public since 2007. Thousands of samples have been done on both research and commercial farms in NY and throughout the entire country and Canada. The CSHT was originally designed for use in commercial vegetables crops but has utility for other crops as well; work is now underway to tailor the CSHT more specifically to perennial crops like berries.

This chapter discusses using the Cornell soil health test to understand and evaluate soil processes important in general crop growth and production including berries. It builds upon and complements some of the ideas presented by Harold van Es in Chapter 1 "Introduction to Soil Management in Berry Production".

Acknowledgements

The Cornell soil health "team approach" to understanding real life soil/plant issues has been highly effective. The team leaders from various disciplines (Crop and Soil Science, Horticulture, and Plant Pathology) help balance the focus of the investigations by bringing expertise from their discipline. Collaborating growers, extension educators and field staff force the discussion back to "on the ground" issues facing growers. This work would not have been possible without their input or the support of the Cornell Soil Health program sponsors: Northeast Region SARE, the Northern NY Agricultural Development Program, the NYS IPM Program, the NY Farm Viability Institute and Cornell University Cooperative Extension.

Soil health is…

Doran and Parkin (1993) define soil health as, "the capacity of the soil to function … chemically, biologically and physically". These are qualitative characteristics. Soil quality can't be measured directly but we can indirectly measure the functions that make up soil quality by measuring important indicators in the chemical, biological and physical arenas of soil function.

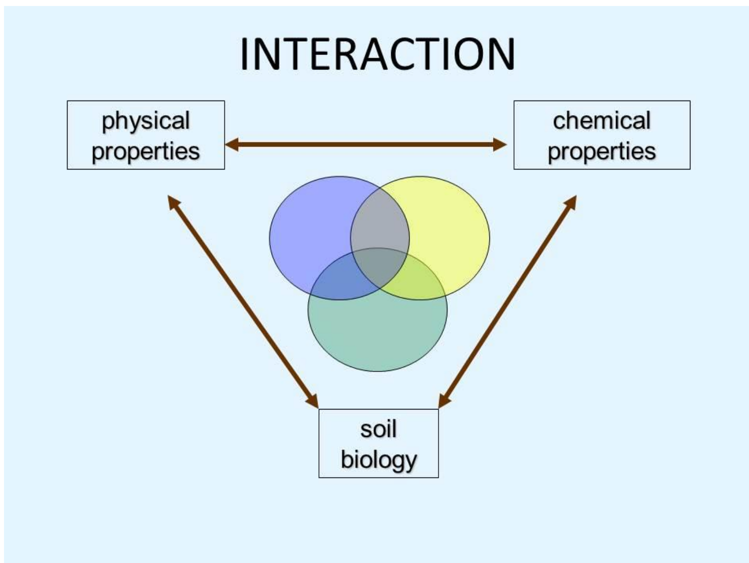
Characteristics of healthy soils

Healthy soils are easy to spot from a distance- the crops growing on them look uniform and vigorous. Closer inspection allows us to list important features of the soil. These features highlight soil processes and functions that benefit vigorous plant growth and support resiliency through balanced functional behavior. Characteristics of a healthy soil are 10-fold and include things like having good soil tilth (physical structure), having sufficient rooting depth, good water storage and drainage, containing sufficient (but not excessive) nutrients, free of chemicals that might harm plants, containing low populations of plant disease and parasitic organisms, having high populations of beneficial organisms, having low weed pressure, showing high resistance to being degraded and exhibiting resiliency (the ability to recover quickly from adverse events). More and more extreme weather events are occurring; a healthy soil has the resilience needed to recover from the effects of these types of events quickly.

Conversely, signs of poor soil health would include cloddy and hard soil at planting, poor seedbeds, rapid onset of stress or stunted growth during dry or wet periods, poor growth of plants, declining yields, high disease pressure and signs of runoff and erosion. Our experience with healthy, productive soils allows us to recognize degraded soils.

Soil behavior is dynamic - we understand that any single measure of soil behavior must also be considered in an ecological context of interaction (Figure 31). This complexity is what we hope to understand using the information we obtain from soil health testing. As scientists, we are reductionists, first de-constructing and learning about the parts, then putting the information back together towards a whole understanding- this is the holistic approach to soil health testing. The soil health team approach is to identify which soil functions are impaired through testing and then adapt field management to address them.

Figure 31. *Soil health is an expression of the physical and chemical properties of soil in conjunction with soil biology. These soil properties interact with the growth of plants to create a complex soil ecology.*



Soil interactions – an example

Why does hard soil reduce rooting? It is not a straightforward simple effect. The answer is complicated due to the interaction of many factors. Ultimately, we can use this information to our advantage as we measure and understand the parts of the whole. Below is an example. Blue text indicates physical properties affected; orange indicates biological processes.

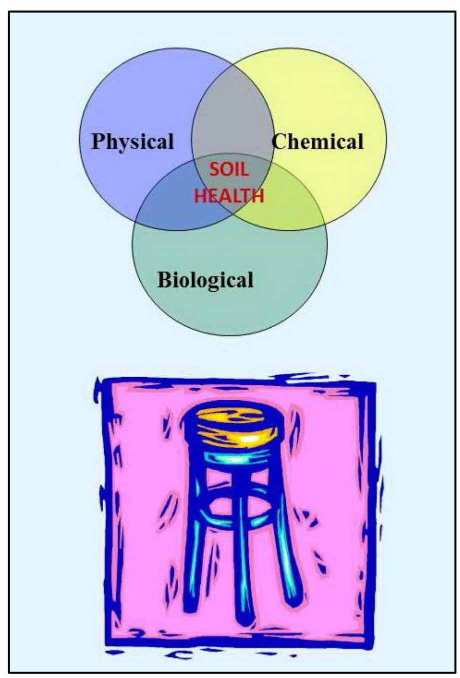
Hard soil reduces rooting:

- **Compacted, dense soil layers restrict rooting volume to exploit water and nutrients**
- **Compacted soil suppresses beneficial biological processes**
- **Poor drainage reduces rooting and aerobic biological processes**
- **Compaction increases root diseases and denitrification losses**

Soil problems on NYS farms (and other farms in the NE region) are not only nutrient concentration issues but often fall into what is called “sick soil syndrome”. One commercial vegetable farm in NY was evaluated using the Cornell soil health test and found to be suffering from this syndrome. The field tested very high in nutrients but as you can see from the photo montage (*Figure 32*) it has very poor stands. Key issues discovered on this intensely used soil were low organic matter content, soil compaction increasing and with that decreased water infiltration. The soil began exhibiting reduced water holding capacity and became drought prone. There was more going on in this field than a simple lack of soil fertility; the Cornell soil health test was developed to further elucidate what is happening in soils like these. Simply adding more fertilizer nutrients would not help the plants to grow.

Figure 32. *A field exhibiting "sick soil" syndrome is being discussed by Extension Vegetable Specialist Carol MacNeil, Cornell Cooperative Extension Vegetable Program.*

Let's look at soil chemical testing. Soil lime requirements and nutrient recommendations have been developed for all major crops. Growers also test for foliar nutrient levels in berries and other high value commodities. Thus much progress has been made to determine nutrient sufficiency levels in the soil (and the plant) and we can even provide recommendations of how much of each nutrient to add to achieve non-limiting soil and foliar test levels. This technology has been developed to become the standard for soil chemical nutrient assessment since World War II. We now recognize that we need to measure soil physical and soil biological parameters in addition to chemical levels. The "three-legged stool" is a useful analogy to describe the strategy of measuring soil parameters in more than just the single chemical arena. If any one of the stool "legs" is weak, the stool can tip over; if all legs are strong, the stool is stable and balanced. A healthy soil is also <u>balanced</u> and therefore provides for crop resiliency to stress. If we can 1) measure soil indicators to identify constraints, then we can 2) optimize our soil management.



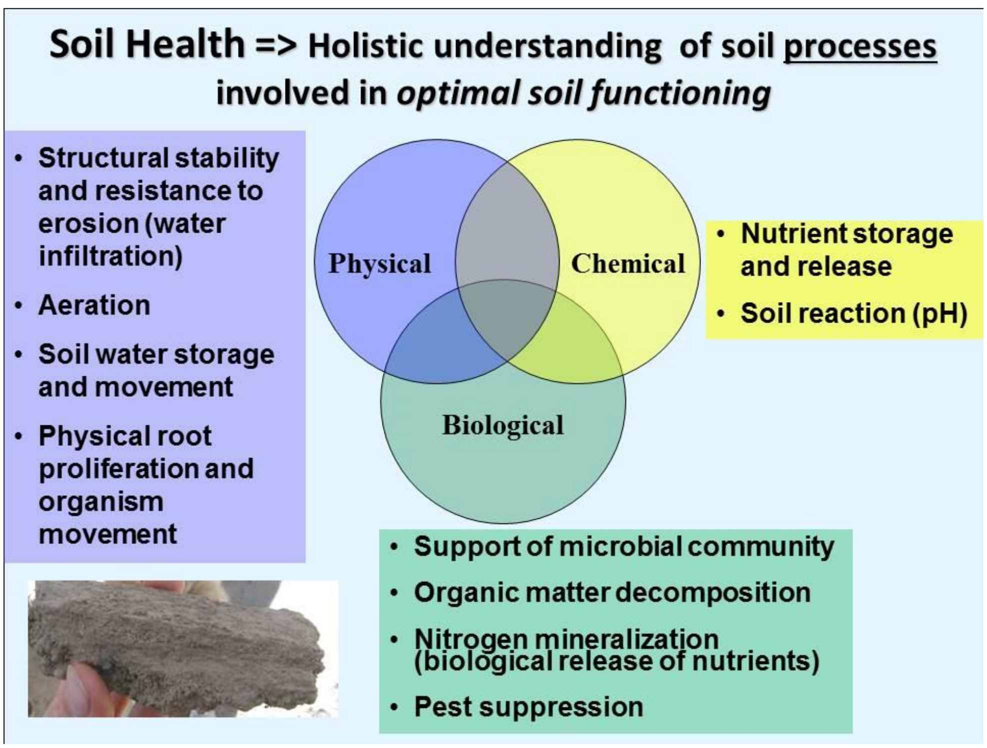
After identifying essential soil functions a testing strategy was developed to quantify these parameters. This was the first step in developing a means to evaluate and manage soil health. The second step involved how to use the information collected to manage soils in such a way as to address measured constraints.

To understand the whole soil ecology, we first de-constructed the soil chemistry by listing the processes which it governs (Figure 33). Much work has been done in the last 75 years to understand nutrient requirements for maximizing growth of various plant types. In the holistic context, we must recognize that chemical storage and release (availability) is also mitigated by soil biological processes. Each of the soil biological functions listed here are key functions to understand and measure. The soil physical structure is often called the "house" for microbes and plant roots to live and function in. Robust tilth allows air and water exchange and subsequent water storage. Roots must be able to penetrate soil layers to obtain water and nutrients there for resiliency to drought.

As previously mentioned, soil chemistry involves nutrient release and storage; this function is mediated to a greater degree by soil pH but is also strongly influenced by both the physical structure as well as soil biology.

Soil biology encompasses support of a beneficial microbial community contributing to organic matter decompositions and nitrogen mineralization leading to the biological release of nutrient leading to plant growth. This beneficial microbial community also lends itself well to suppression of pests.

Figure 33. *Processes governing physical, chemical and biological aspects of soil.*



The Cornell soil health test (CSHT)

The Cornell soil health test in use today was derived from an elaborate suite of 39 potential soil health assessment indicators. What follows below (*Figure 34*) is the suite of physical and biological indicators selected from among those 39 (along with chemical tests) that comprise the Cornell soil health assessment. These final indicators were selected based on their sensitivity to changes on soil management practices, relevance to soil process and functions, consistency and reproducibility, ease and cost of sampling and finally, cost of analysis.

Soil physical tests appear in blue across the top of the photomontage; these are all laboratory tests apart from the field penetration test. Biological tests appear in green across the bottom. The chart below the photomontage lists the indicator tests along with their related soil processes.

A Modified Morgan extracting solution is used to determine soil nutrient levels. Soil texture determination is used to categorize test results. Each test will now be examined in detail.

Figure 34. *Measured CSHT indicators and their related soil processes.*

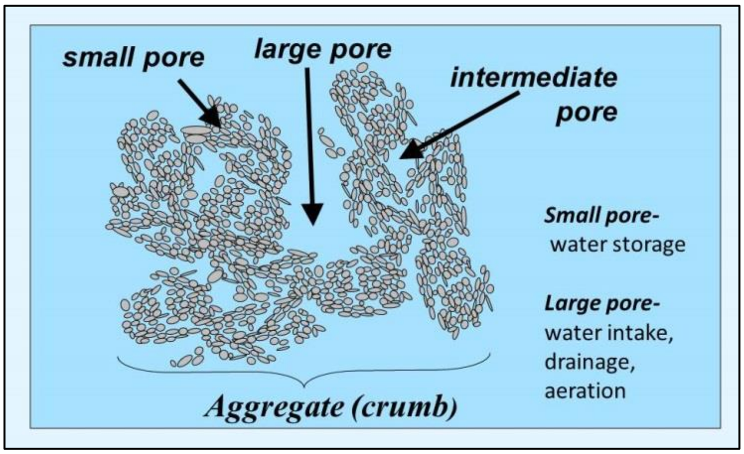
	Indicators	Soil processes
PHYSICAL	Aggregate stability (%)	Aeration, Infioltration, Rooting, Erosion, Crusting
	Available Water Capacity (m^3m^{-3})	Water retention
	Surface hardeness (PSI)	Rooting, Water transmission
	Subsurface Hardness (PSI)	Subsurface pan/deep compaction
BIOLOGICAL	Total Organic Matter (%)	Energy storage, Carbon sequeatration, Water retention
	Active carbon (ppm)	Soil biological activity
	Potentially mineralizable nitrogen (PMN)	Nitrogen supply capacity
	Root health rating (1-9)	Soil-borne pest pressure/disease suppressiveness
CHEMICAL	pH	Nutrient availability toxicity
	Extractable phosphorus (ppm)	Phosphorus availability/run off potential
	Extractable Potassium (ppm)	Potassium availability
	Minor elements	Minor element availability/toxicity

Soil Physical Indicators

The "Soil House"

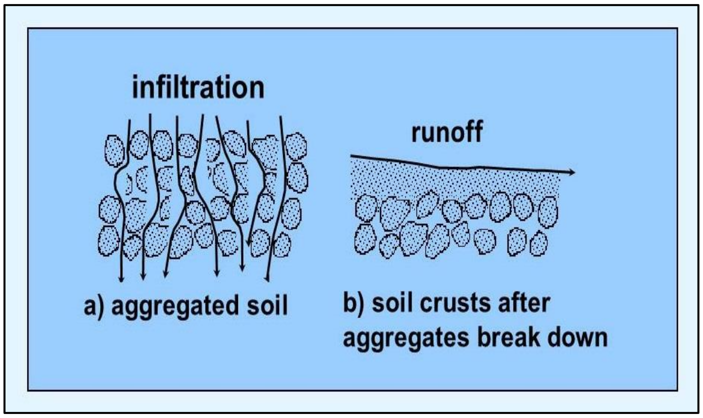
Soil aggregates (or crumbs) are made up of very small soil particles held together by cementing agents and biological glues. Robust soil biological activity produces compounds and by-products ("glues") which contribute to this aggregation. A medium sized soil crumb can be made up of many smaller ones. In a well aggregated soil these different sized crumbs allow for a range of pore sizes (*Figure 35*). The different sized pores perform different functions. Large pores (macropores or biopores) allow for rapid air and water transfer while smaller pores store water over time. Soil inhabitants of all sizes live and travel through the water stored in these different sized pores.

Figure 35. *A medium sized soil crumb made up of many smaller ones. Very large pores can occur within and between the medium size aggregates.*



As water infiltrates rapidly between the large particles in the well-aggregated soil structure shown on the left in Figure 36 stale air is forced out of the pores. As the water continues to percolate down, fresh air is drawn into the soil from the atmosphere. This is the desired fate of water reaching the soil. However, as these aggregates break down they become "self-clogging" and the soil closes up, causing soil crusts to form. This crust inhibits air exchange which can lead to the soil becoming anaerobic. The right side of Figure 36 shows a crusted soil surface where the compacted zone facilitates surface water run-off. The water that runs off the field can erode the soil and transport large quantities of topsoil to ditches and streams.

Figure 36. *Model of soil structural breakdown*.



Maintaining good soil aggregation allows not only rain capture but also facilitates drainage via the large pores between crumbs. This "open soil" is widely recognized as a key indicator of good soil quality. Soil surface crusting is surface compaction with destruction (or infilling) of the large pores which impairs water and air movement.

Soil structure affects many soil processes which are facilitated by an open aggregated soil. Note that as soil becomes compacted the large pores are destroyed first. Resulting dense, compacted soil often leads to sluggish plant growth. Soil crusts (surface compaction) reduce infiltration leading to runoff and erosion. Decreased infiltration means less water storage and air exchange. Reduced root penetration reduces the soil volume explored for water and nutrients. It is important to note that plants *can* overcome hard soil but must expend extra energy to do so at the expense of shoot growth and/or fruit production.

Figure 37. *An example of soil structural breakdown.*

Figure 37 above details some field examples of soil structure break down. On the bottom left is a photo of a vineyard in California where managers are experimenting with various surface maintenance strategies between rows of grapes. Note in the standing water to the left of the photo where the soil is crusted; in the middle row where soil has been loosened using various techniques water is infiltrating better. The photos just above it are of a potato field. This intensively cultivated field shows signs of surface crusting and sealing that lead to erosion. Digging into the soil at right we see that there is also a dense subsoil layer caused by excessive use of a disk cultivator.

From this photoset it can be seen that in field crop production we typically manage the entire soil area, whereas in a vineyard or berry field we may manage the row area differently than the between row area.

CSHT wet aggregate stability test

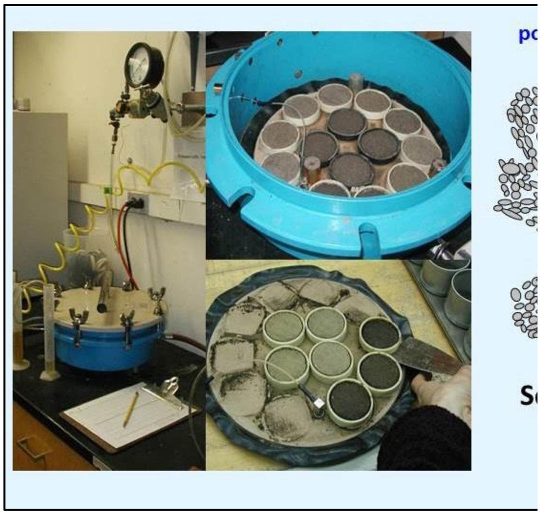
The CSHT aggregate stability test is a way of testing soil stability in the lab using simulated rainfall. Aggregate stability, by definition, is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing a known weight of soil aggregates between 0.25mm and 2.0mm. Unstable aggregates fall apart and pass through the sieve. The fraction of soil remaining after the water drops are applied during the test interval determines the percent aggregate stability. Pictured in Figure 38 are results from a CSHT wet aggregate stability test which delivers 1.25cm (1/2 inch) of simulated rainfall in 5 minutes on to the sample crumbs. The results pictured are from a long-term tillage research study (14 years of continuous corn) that compares fall moldboard plowing with no-till. On the left is the 14-yr continuous plow till soil; on the right a no-till production system. Qualitatively (and visually) it is clear that starting with the exact same soil in both cases, the soil from the no-till soil on the right under continuous corn production has a much higher stability value (72%) vs. the plow till soil on the left (22%). The long-term plow till soil with the low soil stability result in the laboratory test (22%) would be susceptible to the surface sealing and crusting discussed above.

Figure 38. *CSHT Wet Aggregate Stability testing using the Cornell Sprinkler to simulate rainfall.*

CSHT available water capacity test (AWC)

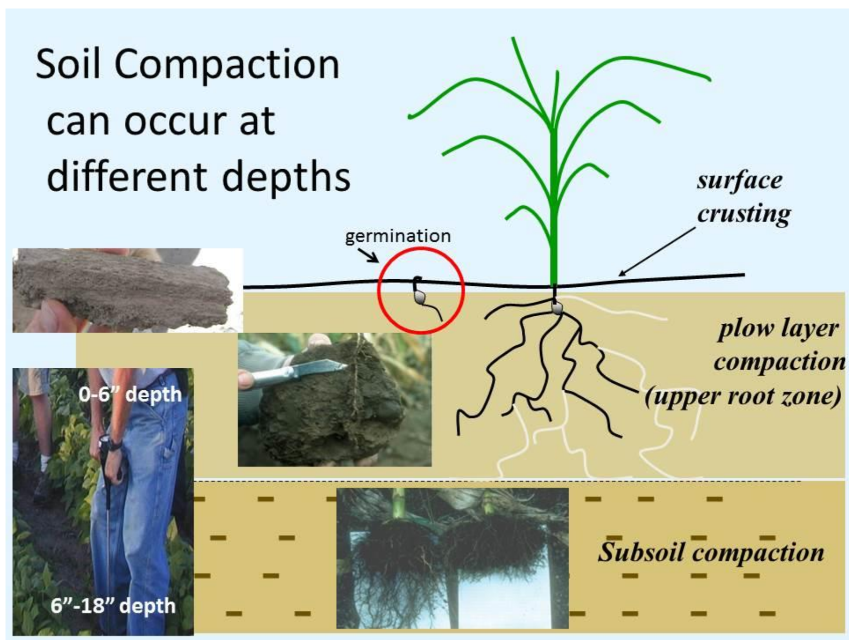
Available water capacity, or AWC, is defined as the difference in water content of soil at 0.1 bars (field capacity) and 15 bars (permanent wilting point). Water storage is influenced by texture, organic matter and soil structure. The field capacity measurement corresponds to pores 30 microns in diameter (the diameter of the average human hair.) The pores larger than 30 microns are emptied into gravity in 2 days (Figure 39). Field capacity is defined then as the upper limit of water storage. The 15 bar soil water content is the lower limit of water storage, corresponding to pores 0.2 microns in diameter. At the permanent wilting point, or PWP, these tiny pores hold water more strongly so most plants can overcome.

Figure 39. *Available water capacity operatus and schematic of gravitational pore draining.*



CSHT field penetration test

Our one field measurement in terms of physical soil properties is the soil compaction test. When each soil sub-sample is collected we also record the greatest soil hardness encountered through the two depth intervals using a soil penetrometer. Determining where compaction zones occur gives us information to target our soil management (*left in picture*). The 0 to 6" depth is referred to as the plow layer or surface or active layer; the 6 to 18" layer is referred to as the subsoil. It is important to isolate these 2 depths to better plan for soil management.

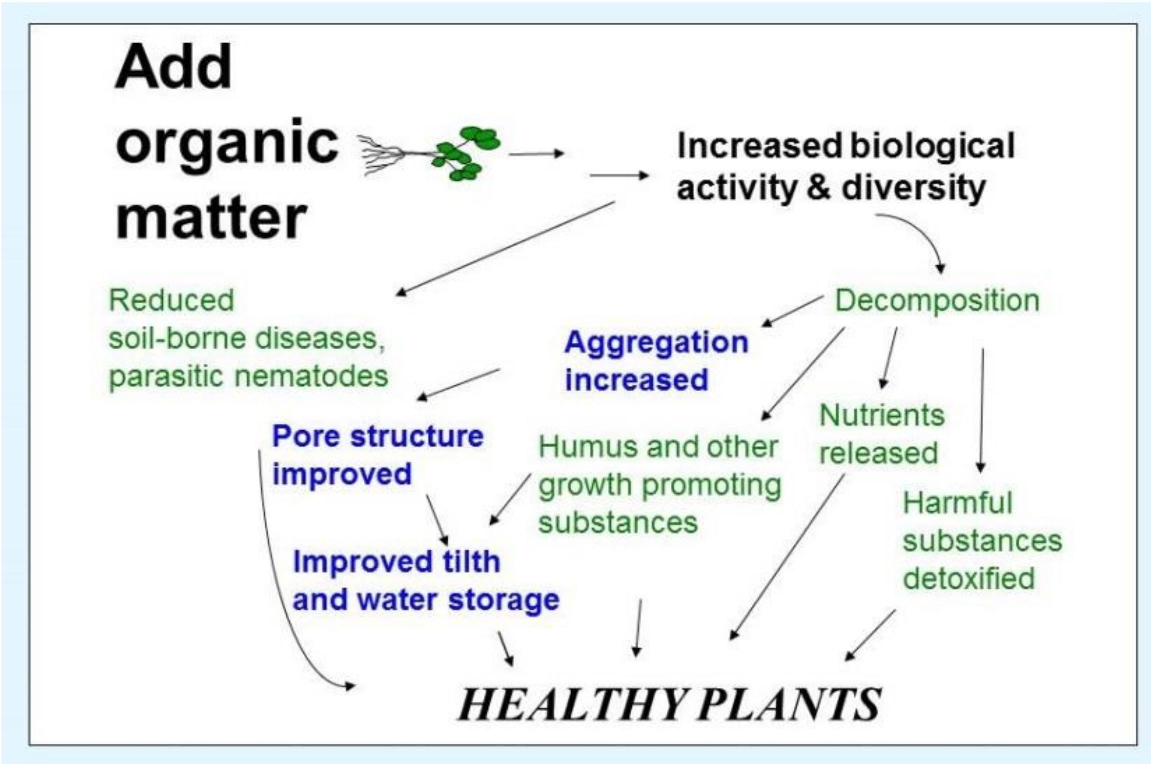


Soil biological indicators

These indicators take us back to the soil ecology with organic matter (food) as the driver of these essential soil processes. Each process is important as a link in the chain leading to resilient soil supporting healthy plants.

The addition of organic materials can contribute to enhanced soil physical processes just discussed (*Figure 40*). Now we'll move to a discussion of the biological processes.

Figure 40. *Adding organic matter (OM) affects soil processes (modified from Oshins, 1999).*



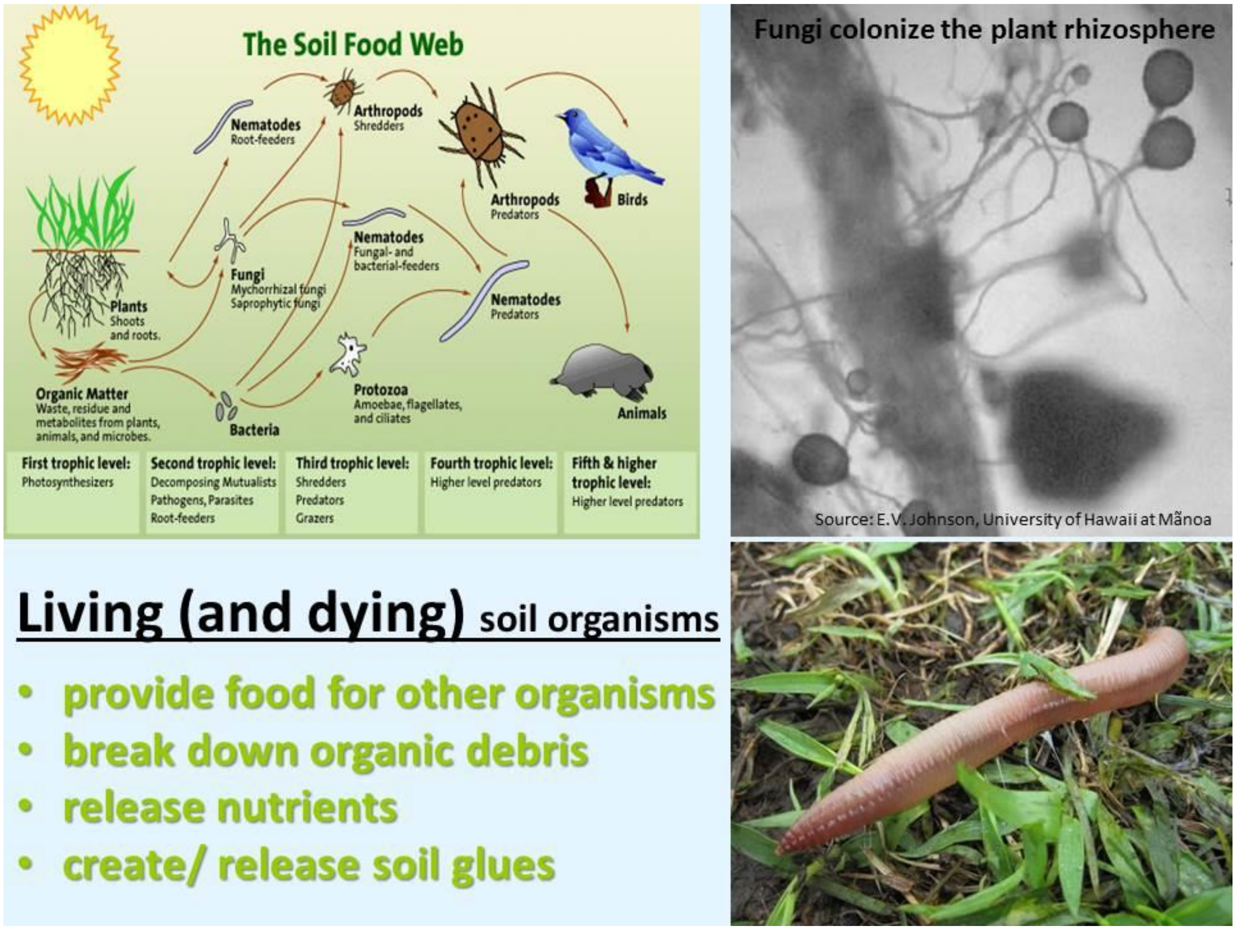
As mentioned in Chapter 1, there are three general "types" of organic matter in soils:

- ***Living*** - soil organisms and plant roots.
- ***Dead*** - recently dead soil organisms and crop residues provide the food (energy and nutrients) for soil organisms to live and function. Also called "active" or "particulate" organic matter.
- ***Very Dead*** - well decomposed organic materials, also called humus. Humus contains very high amounts of negative charge and has high water-holding capacity.

These categories of organic matter are used to simplify a very complex subject- soil organic matter. Some living organisms perform vital functions for plants and others can cause damage. The useful competition between living organisms can be mitigated by the food available for them. Complex humic substances can be long lived and perform vital water storage, loosening/ lightening functions and nutrient storage. All three types of soil organic matter play important roles in helping produce high yields of healthy crops.

The soil biological life cycle is a battleground among the creatures found there (*Figure 41*). Many of the nutrients bound up in the soil biota become available upon death to other organisms or plant roots.

Figure 41. *Living (and dying) soil organisms.*



Upper right- Fungi colonize roots and provide benefits to the plant- increased nutrient uptake, protection against other soil microbes. Microbe glues and earthworm "slime" (lower right) bind soil particles. Important soil processes are mediated by these organisms and we measure a chosen group.

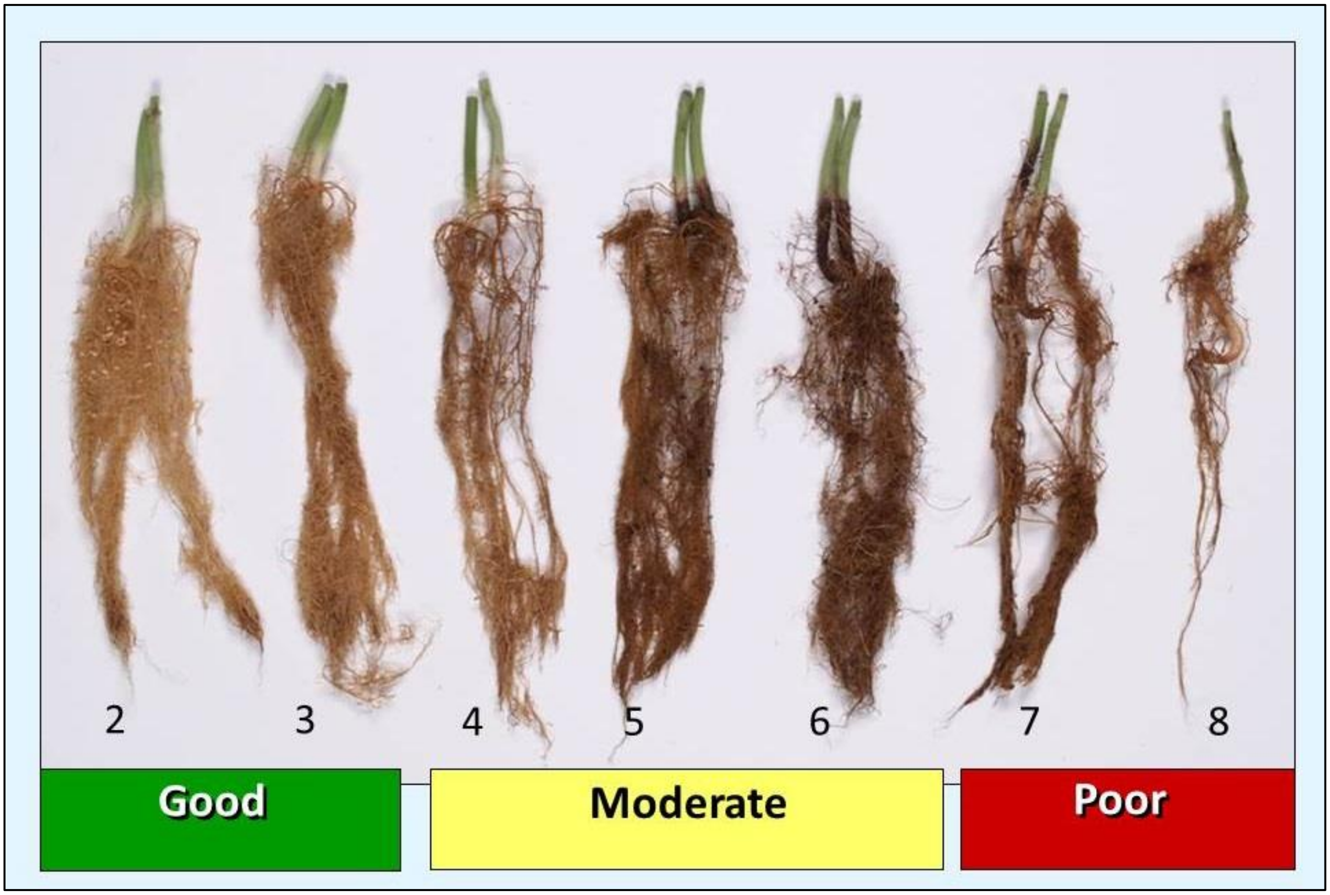
CSHT potentially mineralizable nitrogen test (PMN)

PMN is an indicator for the capacity of soil microbes to convert nitrogen tied up in complex organic residues into plant-available forms (ammonium and nitrate). This test reveals the ammonium liberated from soil organic nitrogen over a one week incubation period. High values suggest a robust population of organisms which contribute to this conversion as well as a food source for them. This is not a test to determine the nitrogen supply levels of the soil but instead it is an indicator of activity with high numbers suggesting the presence of useful organisms and substrate for them to use. The technique used requires soil be measured for ammonium-N at sampling (time zero) and again after a 7-day incubation period.

CSHT soil bioassay with bean test

Another test done with living organisms is the root bioassay with a green bean variety highly susceptible to soil pathogens. This assay is used to evaluate the soil disease suppression index. Each soil sample is planted out in replicate with the susceptible bean variety and allowed to grow for 4 weeks in the greenhouse. Plants are removed from their containers and soil is washed away form the roots. Roots are then rated on a score of 1 to 9 (*Figure 42*). A robust soil will have biota which outcompete disease producing organisms with the result of "clean" roots. Note the bean seeds are treated with a combination of fungicides prior to planting to prevent seed decay and/or seedling diseases that might have an impact on test results.

Figure 42. *Root health rating scale for soil bioassay with bean.*



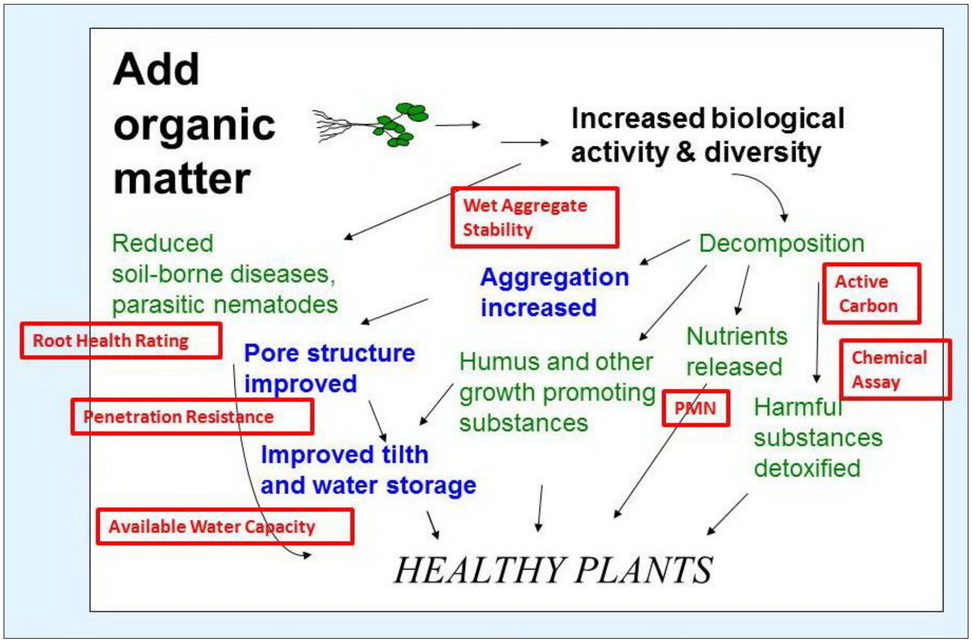
Active carbon test

The recently "dead" portion of soil organic matter is measured using the active carbon test. The active carbon test (*Weil et. al., 2003*) is an indicator for the fraction of carbon and nutrients in total organic matter that is actually available for use by the soil food web and plants. This indicator shows a response to soil management sooner than total OM% changes. The "recently dead" soil life becomes food and energy for other soil life. The material that is available for soil organisms to use can be quantified when chemically "burned" with purple potassium permanganate. A high level of oxidizable material reduces the amount of purple color in the permanganate test solution which we can read with a colorimeter (*right*).

The very dead humic fraction of soil represents a "black box" of compounds. These complex materials really are the long-lasting "house" of soil structure. Moderate amounts of humic substances benefit all soil types. These substances do not typically provide significant energy to the soil biota as does the smaller compounds revealed through active carbon testing. Humus, like clay, can hold a lot of cations; it also increases soil water holding capacity. Clay soils are "loosened" and soften by organic residues (humus).

Back to the soil ecology with organic matter (food) as the driver of these essential soil processes. Each process is important as a link in the chain leading to resilient soil supporting healthy plants. Note that these processes occur at different rates and times based on the composition of the initial food source. These issues (and more) will be discussed in the next chapter which focuses on how to maximize these positive processes using various organic materials and composts.

Figure 43. *An update of Figure 40 showing where the Cornell Soil Health Assessment test indicators are used to evaluate these soil processes.*



Note that the boxes in red in Figure 43 list the Cornell soil health tests just discussed for use in soil health assessment. The easily measured indicators listed represent these essential processes. From these indicators, we can determine sub-optimal or constrained levels of soil function.

CSHT rapid soil texture test

The rapid soil texture test is used to determine the soil's textural class as a percentage of sand, silt, and clay. Soil textural class is used to aid in interpretation of the above mentioned indicators. The test used is one developed by *Kettler, Doran and Gilbert (2001)* where soil is oven dried and sieved; a sample of known weight is then vigorously shaken for 2 hours in a tube with a 3% soap solution. The samples are then rinsed onto another sieve where the material is rinsed through the sieve using fingers or a rubber policeman; sand remains in the sieve and is collected for drying. The water and silt and clay particles passing through the sieve is collected in a large beaker. This mixture is stirred and then allowed to settle for 2 hours, the liquid with its suspended clay particles is poured off and the settled silt is collected and weighed.

For a more in-depth understanding of the development and use of the Cornell Soil test see *Cornell Soil Health Assessment Manual, 3rd edition.*

The Cornell soil health test report

The product of the above testing is contained in the Soil Health Test Report (below *left*). The reported test values are taken to a database and sorted by soil textural class for interpretation. The rating column to the right of the reported values shows where the values falls in the data distribution (out of 100). Color coding of red, yellow and green represent the lowest 30% of the distribution, the middle 40% and the upper 30%, respectively. For values in the lower 30% of the distribution (coded in red), the soil functional constraints are listed. To develop a deeper understanding of the CSHT scoring functions see "*Cornell Soil Health Assessment Manual, 3rd edition*".

CORNELL SOIL HEALTH TEST REPORT				
	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	22.3	10	aeration, infiltration, rooting
PHYSICAL	Available Water Capacity (m/m)	0.13	25	water retention
PHYSICAL	Surface Hardness (psi)	42	94	
PHYSICAL	Subsurface Hardness (psi)	390	1	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	3.9	42	
BIOLOGICAL	Active Carbon (ppm) [Permanganate Oxidizable]	614	27	Soil Biological Activity
BIOLOGICAL	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	6.3	2	N Supply Capacity
BIOLOGICAL	Root Health Rating (1-9)	3.2	75	
CHEMICAL	pH (see Nutrient Analysis Report)	6.1	67	
CHEMICAL	Extractable Phosphorus (see Nutrient Analysis Report)	2.6	44	
CHEMICAL	Extractable Potassium (see Nutrient Analysis Report)	78.8	100	
CHEMICAL	Minor Elements (see Nutrient Analysis Report)		100	
	OVERALL QUALITY SCORE (OUT OF 100):		48.9	Low
	Soil Textural Class:==> clay loam			
	SAND (%): 21.0		*SILT (%): 42.0*	*CLAY (%): 37.0*

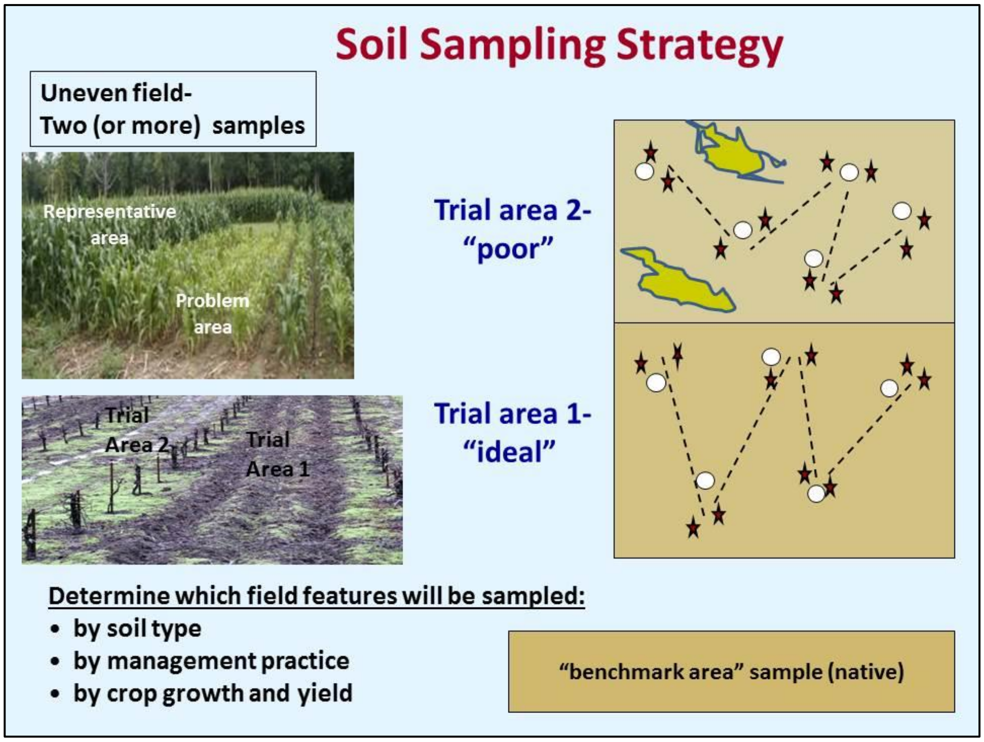
The utility of soil health evaluation

Soil health testing investigates the complex interaction between physical, biological and chemical processes. The CSHT suite of indicators allows for the comprehensive, quantitative assessment of a soil's health status. Note that no direct management recommendations accompany the CSHT results; rather management tactics are tailored to individual crops, farms, and circumstances. Results from the soil health test allow for 1) education about soil health concepts, 2) monitoring effects on soil health due to management (e.g., NRCS Conservation Security Program), and 3) targeting of management practices.

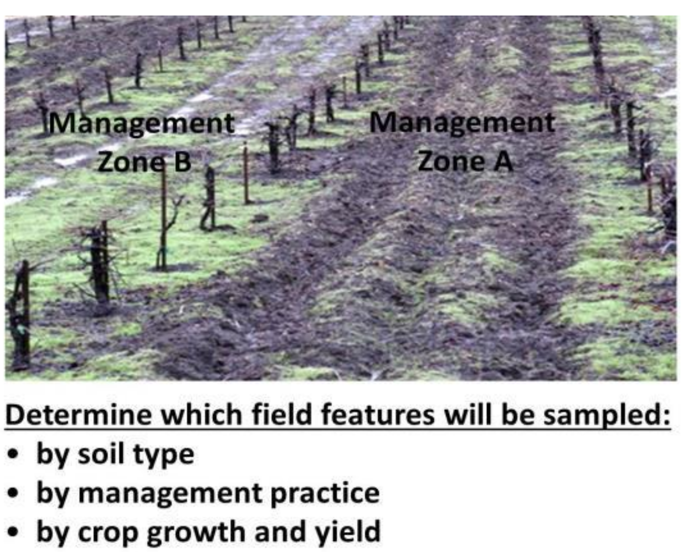
Information from the measured indicators in the CSHT gives us a broader suite of data to evaluate soil performance. Understanding the utility of each of these measured parameters singly and together respects the holistic nature of soil ecology. Now we must use the information to develop a management scenario that fits the needs of the grower and available resources.

In terms of berry crops utility of soil health evaluation has just begun to be explored; growers considering establishment of new plantings are likely to benefit most at present from use of this test. The perennial nature of berry crops makes it critical to have the best possible soil health *prior to planting* as mitigation of problems after planting can be extremely difficult. That being said, there is also utility for this test in terms of its use in established plantings as a diagnostic tool for discovering production issues as they relate to soil health. What still remains to be determined are potential management practices that may be implemented post-plant that will have positive impacts on sub-optimal or constrained levels of soil function. As we introduce a soil management strategy for berry crops using the information obtained in the Cornell Soil Health Test we will focus on agronomic approaches to soil building in "off-berry" years on the field rotation.

Collecting a CSHT sample



The best time to collect a soil sample for submission to the soil health testing lab is when the soil is in a fully functional or active condition. Sampling a soil when frozen or hard during an extended drought period is not recommended. It is important that the soil be at field capacity when sampling so that meaningful soil penetration data may be collected. Sample only the surface soil from 0-8" deep, scraping away any loose organic debris from the top of the sample. Remember that when you collect the subsamples which comprise a sample that you are asking a question for which you will receive an answer. So sampling the entire field randomly will give values representing the gross mean of that field for each parameter (*right*). Trial area #1 in the figure indicates a uniform field where only one sample would be collected; this sample would be comprised of several unbiased, representative sub-samples which are then combined into one composite sample. White circles indicate sub sample collection points; red stars indicate associated penetrometer reading sites. At each stop in the field one soil subsample is collected and 2 penetrometer readings are recorded. At each stop, with one smooth push, penetrate through to a depth of 18" record the highest penetrometer reading (value) encountered for the 0 to 6" and 6 to 18" depth. Soil could also be collected for Trial area #2 in the figure as a separate sample to determine possible soil health factors causing the poor plant performance. Also, a benchmark sample taken just off the production area can be used to determine the "natural" or background soil parameter values to compare to the values obtained under production in the poor and ideal areas.

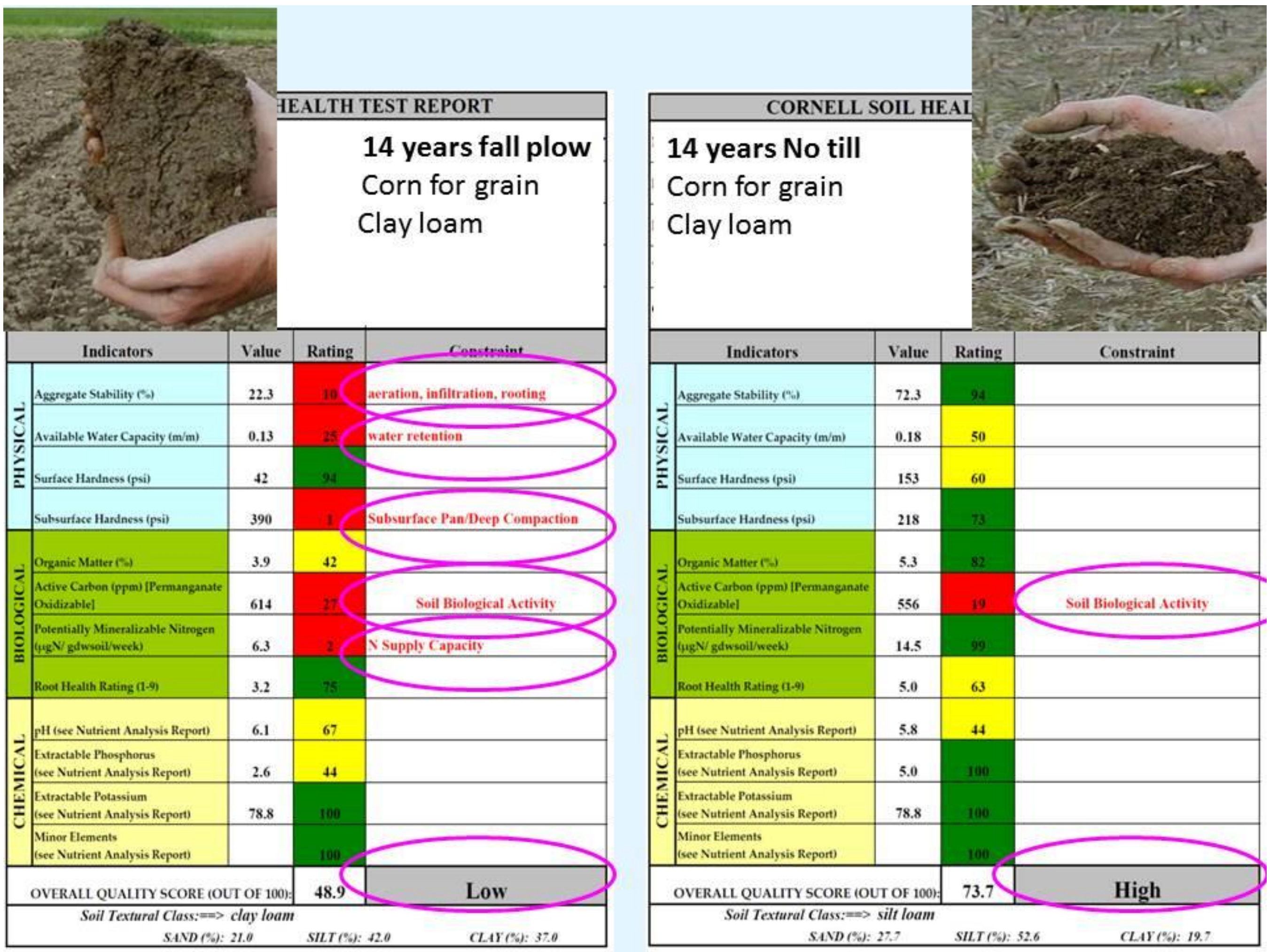


Contrasting soil types, soil management, crop growth or yield can be evaluated by collecting 2 (or more) separate soil samples. In the figure at left, we might collect 2 separate soil samples from management zone A and management zone B. In bedded situations like some berry production scenarios, we might want to collect one sample near the plants in the beds versus another sample collected next to the bed further from the plants.

An example from real life

Back to the long-term research corn grain trial with moldboard plow tillage versus no-till soil management. By submitting samples from contrasting areas of interest we can learn from the Cornell Soil Health Test Report the effects of applied management. We can see differences in soil appearance in these samples taken from our tillage research plots at Cornell's Baker Research Farm in Willsboro, NY. Let's sample these plots and look at the Cornell Soil Health Test Reports (*Figure 44)*.

Figure 44. *CSHT test results for plow till vs. no-till corn research project, Willsboro, NY.*



	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	22.3	10	aeration, infiltration, rooting
	Available Water Capacity (m/m)	0.13	25	water retention
	Surface Hardness (psi)	42	94	
	Subsurface Hardness (psi)	390	1	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	3.9	42	
	Active Carbon (ppm) [Permanganate Oxidizable]	614	27	Soil Biological Activity
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	6.3	2	N Supply Capacity
	Root Health Rating (1-9)	3.2	75	
CHEMICAL	pH (see Nutrient Analysis Report)	6.1	67	
	Extractable Phosphorus (see Nutrient Analysis Report)	2.6	44	
	Extractable Potassium (see Nutrient Analysis Report)	78.8	100	
	Minor Elements (see Nutrient Analysis Report)		100	
	OVERALL QUALITY SCORE (OUT OF 100):		48.9	Low
	Soil Textural Class:==> clay loam			
	SAND (%): 21.0		*SILT (%): 42.0*	*CLAY (%): 37.0*

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	72.3	94	
	Available Water Capacity (m/m)	0.18	50	
	Surface Hardness (psi)	153	60	
	Subsurface Hardness (psi)	218	73	
BIOLOGICAL	Organic Matter (%)	5.3	82	
	Active Carbon (ppm) [Permanganate Oxidizable]	556	19	Soil Biological Activity
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	14.5	99	
	Root Health Rating (1-9)	5.0	63	
CHEMICAL	pH (see Nutrient Analysis Report)	5.8	44	
	Extractable Phosphorus (see Nutrient Analysis Report)	5.0	100	
	Extractable Potassium (see Nutrient Analysis Report)	78.8	100	
	Minor Elements (see Nutrient Analysis Report)		100	
	OVERALL QUALITY SCORE (OUT OF 100):		73.7	High
	Soil Textural Class:==> silt loam			
	SAND (%): 27.7		*SILT (%): 52.6*	*CLAY (%): 19.7*

Here we learn the effects of long term moldboard plowing for grain corn versus no till on this clay loam. In the long-term plow example on the left, we see that the soil physical properties have been negatively affected compared to the no till soil management as have the biological properties. Note however that even in the no till plot the "steady diet" of corn stover has maintained soil organic matter but impaired active carbon levels. This field started out as alfalfa hay- we see that no-tilling maintained a healthy soil (high score) while the continuous moldboard tillage had several measureable negative effects on soil processes (low score).

Developing a management scenario

A four-step process for interpreting and using the information from the CSHT report has been developed (*Figure 45*).

Figure 45. *Cornell Soil Health Test Report Field Management Planning Sheet.*

The **first step** in Soil Health Management Planning involves defining the grower's background, desires and resource options. **Step Two** asks the grower to combine their knowledge of the field with the information on soil functional performance provided in the Cornell Soil Health Test Report to identify field management targets. This sets the context for **Step Three** where different management options to address the identified targets are weighed (Figure 46). This aspect of examining the information provided requires considerable attention and thought to be of the most value. In addition, agricultural professionals (Extension specialists, consultants, growers, researchers) can bring many ideas to the table here and this is a great forum for brainstorming a management scenario. Reliable advances in soil improvement in berry crops have been made by applying sound agronomic practices well known to field crop growers to fields that are in the "off-berry" phase of the rotation.

Ideas from field days, conferences, the media and other growers can be discussed to arrive at a meaningful strategy for the grower. **Step Four** puts the three steps above together to provide an action plan for the grower to move forward with a management objective derived from an adaptive strategy of information gathering (see Chapter 9).

Soil management options for annual crops can be different than those suitable for more perennial plants such as berries due to row spacings, soil bedding designs, placement of mulches, etc. Ag consultants and educators, as well as growers, must continue to learn of the latest technologies and principles available to accomplish field objectives.

Differing commodities or production systems (organic vs conventional, bedded vs flat) require expertise to be shared between the consulting Ag professionals and the grower. Progressive producers rely on sound advice to continue to adapt the soil management to changing markets and the uncertain climate. How to deal with measured soil constraints has to be addressed on a CASE BY CASE, FIELD BY FIELD, GROWER BY GROWER basis.

Summary

The Cornell Soil Health Test was developed by a diverse group of Cornell University faculty, research staff and Extension personnel. Each person brought to the team an expertise that was felt to be incomplete to understand field situations where plant performance was poor even when soil fertilizer nutrients were not limiting. The consensus of the group was a need to identify and measure a broad suite of soil functional processes to understand the soil ecology. A holistic approach to soil process testing to find limitations to soil performance was developed.

Indicator tests were devised or adopted to measure the essential soil physical processes of aeration, water infiltration and retention, soil hardness in the surface and subsurface. Soil biological function was evaluated from total organic matter content, readily oxidizable organic material to fuel the soil biota and a measure of microbial activity via transformation of organic nitrogen material to plant available ammonium. A measure of root disease suppressiveness by the soil microbial community established. The standard plant-available nutrient extraction and quantification test rounds out the soil measurements.

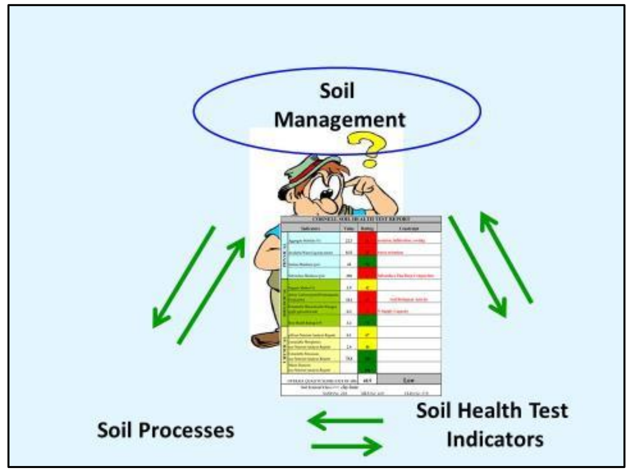
After these processes are measured in the lab, they are scored against a database and the results are returned in the Soil Health Report. The Report uses a color coding to highlight in red the soil processes values that are in the lowest 30% of the values in the database. This information on the Report is then used in the context of developing a soil management plan to holistically approach the constraining soil processes. The grower compares the information returned in the Report to then prioritize management efforts. Knowledge of the best management tools to use to address the identified concerns requires a capacity to obtain information from various sources. This adaptive strategy of soil management is best served with a system of trial application of soil management practices and observation of the results.

Further reading

1. Gugino, B.K., Idowu, O.J., Schindelbeck, R. R., van Es, H.M., Wolfe, D.W., Moebius-Clune, B.N., Thies, J.E., and Abawi, G.S. 2009. *Cornell Soil Health Assessment Manual, 3rd edition*. Cornell University, Geneva, NY.
2. Cornell Soil Health web site: http://soilhealth.cals.cornell.edu/

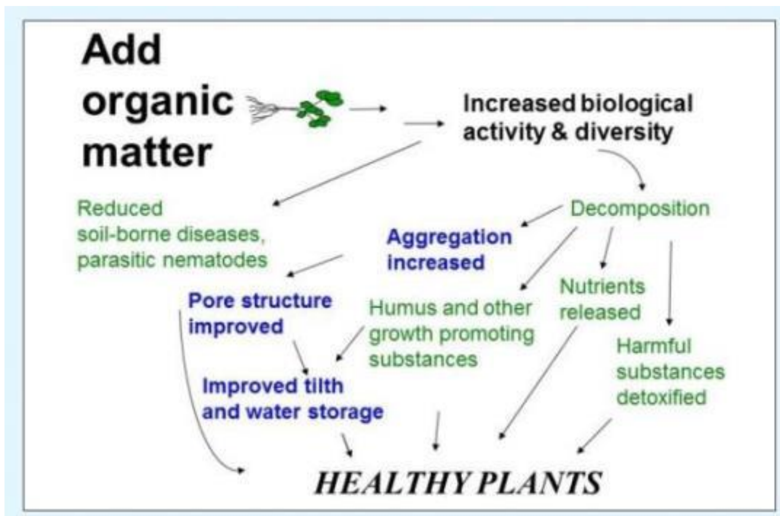
Chapter 9 Improving Biological and Physical Soil Properties in Commercial Berry Plantings – *Robert Schindelbeck, Cornell University*

Let's review



Soil ecology is very complex and full of interaction between the different soil physical and soil biological factors. In order to have some understanding and impact on soil ecology then, it is necessary to take a reductionist approach to the problem, first de-constructing and learning about the parts, then putting the information back together towards a whole understanding. This is the holistic approach to soil health testing. Soil behavior is dynamic- we understand that any single measure of soil behavior must also be considered in an ecological context of interaction.

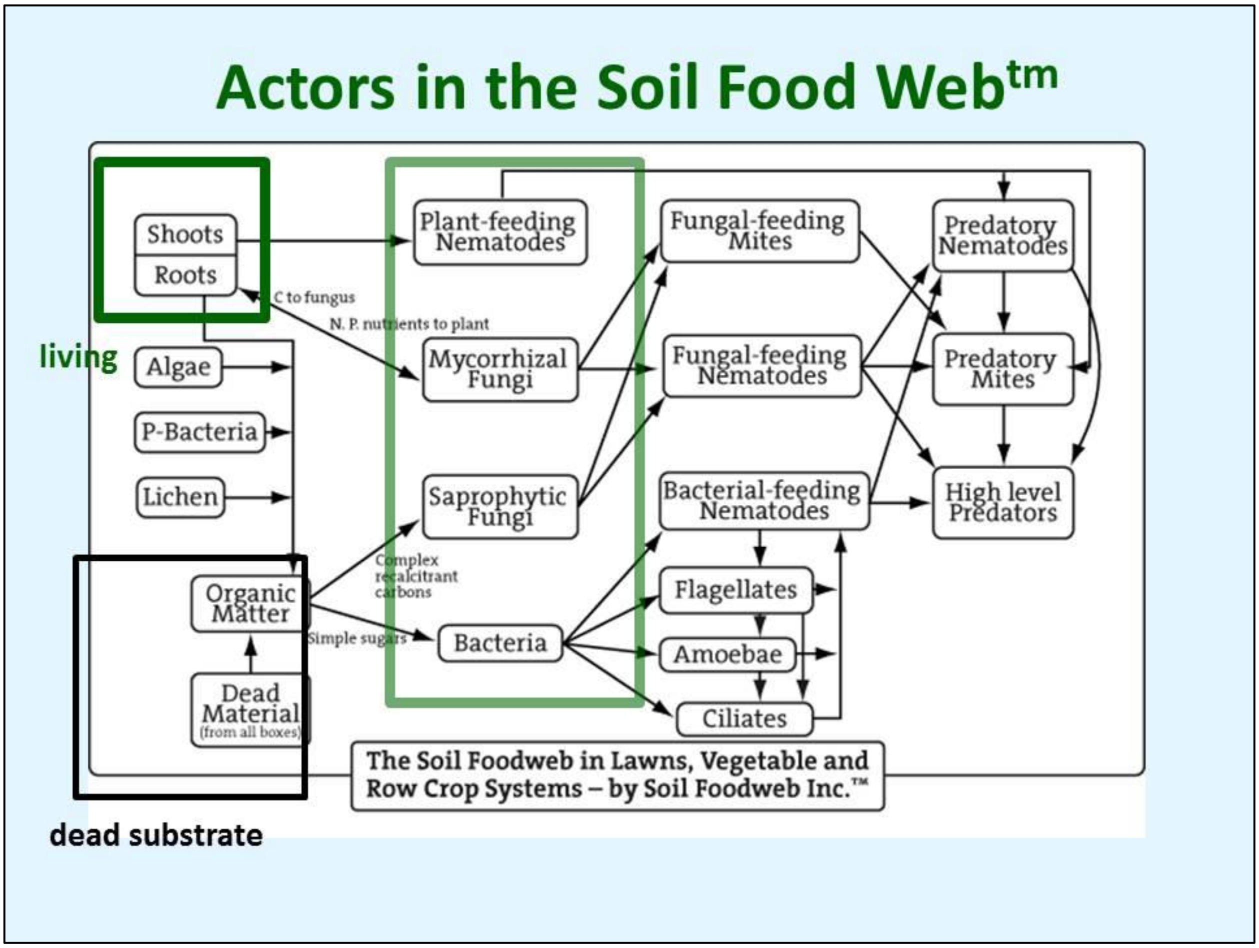
Adding organic matter



Adding organic matter affects soil processes; these include both physical (blue) and biological (green) processes in soil (*right*). Different types of organic matter affect these processes in different ways. When considering soil health management strategies it is important to take this into consideration. For example, what age organic matter would be best to affect the soil health in the way we need? Should it be applied to the surface, mixed in, grown in?

Actors in the soil food web

The actors in the soil food web start with organic matter. These include both living organic matter (shoots and roots) and dead substrate. These are quite variable and have different effects on different organisms. Certain oganisms then may be promoted or restricted by modifying the living and dead substrates.



All organic matter is not created equal

Fresh material (grass clippings, leaves, raw manures). Green and animal manures provide both nutrients and energy-rich food for microorganisms living in the soil. Composting of this material takes place in situ (in the field). Breakdown products help to 'glue' soil particles together to increase soil tilth. Addition of this type of fresh organic matter also favors the rapid bacterial population increases which can lead to N immobilization, causing plants to be N deficient.

Composts (biosolids, biochar, municipal stockpiles). These are long-term, stable materials. Bacteria/ bacterial by-products become a food source for next-level organisms. More stable composts can lighten heavier soils and add water and nutrient storage capacity to coarser soils. Potential for nitrate and phosphate runoff losses and leaching losses from concentrated composts may be high.

We recognize that soil biological processes are affected by the mix of active fuel (living or fresh) and passive stable (humus, or very dead) materials, the diversity of soil organisms and their activities. The interaction of these components is controlled by moisture, temperature, mixing, inorganic nutrients (nitrogen), carbon source, etc. We can affect these processes with our crop and soil management.

Plants and organic debris are part of a dynamic system

Different plants or plant debris composition affect soil biology- note that growing specific plant species can result in introduction of specific compounds into the soil ecology. Healthy soil biotic communities tend to suppress disease causing organisms. Reduced plant stress due to a balanced soil environment reduces plant susceptibility to disease. Plant shoots and roots are capable of producing plant defensive compounds that stress pests. These plants can also enhance beneficial organisms.

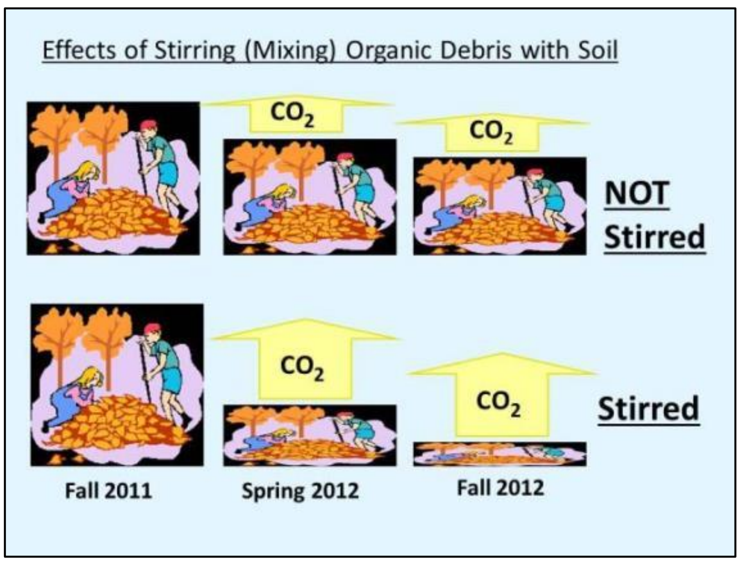
The plant root modifies the rhizosphere environment. Plants contribute nutrients and cellular material to the rhizosphere (estimates up to 20-40% of total plant energy). The root tip loses cells as it passes through the soil. These cells can release their contents and help dissolve nutrients into solution. These cells can also become food for organisms which can provide increased access to nutrients and water protection from disease organisms. Plant roots can singly or symbiotically release compounds which favor the plant needs over competitors' needs.

Plants contribute nutrients and cellular material to the rhizosphere zone around the plant roots. Root hairs are short-lived single cells expanding behind the root tip. These hairs can become infected by bacteria (Rhizobia nodulation). These hairs can entwine with fungal mycelium to increase overall surface area for increased capture of nutrients and water. Dead root hairs burst and release compounds which modify the rhizosphere to facilitate new root hair exploration.

Soil carbon transformations under biologic processes and fungal processes

In a bacterially dominated system, root exudates and plant debris are used as a food source. These bacterial then become a food source for nematodes and actinomycetes. Excess nutrients are mineralized and made available to plants. This is a rapid onset system, characterized by tillage agriculture. Somewhat stable, simple humic carbon compounds can be produced from the transformation of dead organic material or merely remain as recalcitrant cellulose and lignins- compounds that resist further biological use.

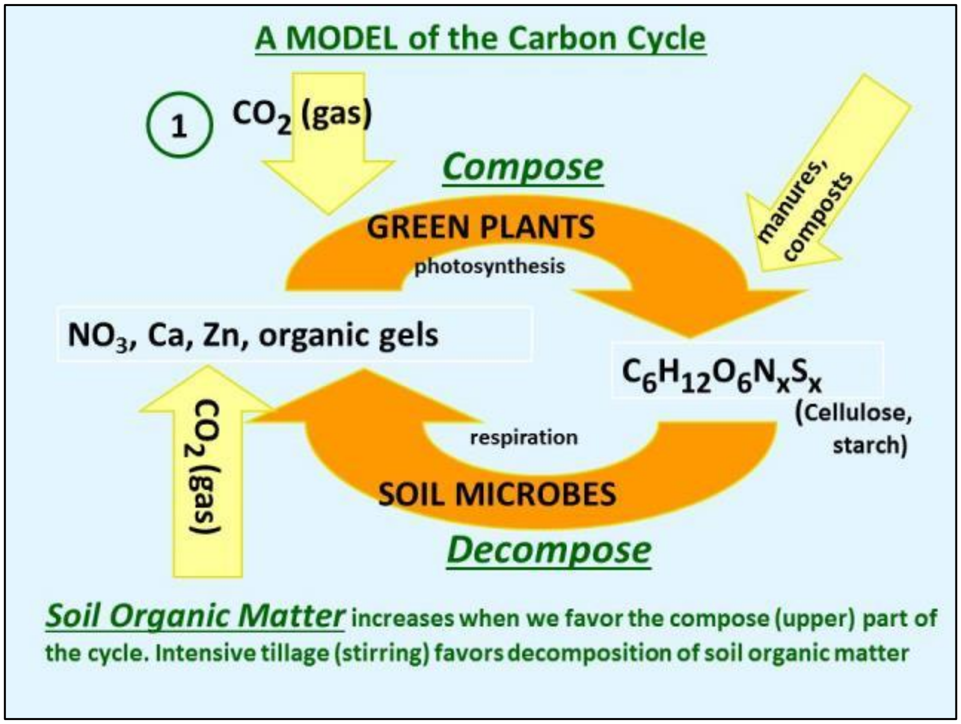
In a fungal dominated system, fungi are the first feeders on rhizosphere compounds and other soil available metabolites. These root associations greatly benefit the plant in water and nutrient uptake and can afford protection against soil-borne disease organisms. These associations develop slowly and are found in undisturbed permaculture environments, such as berry plantings. Complex carbon compounds are sequestered through this "humification" and these durable humic substances can last decades.



The schematic to the right shows the effect of stirring (mixing) organic debris with soil. Across the top leaves are simply collected into a leaf pile in the fall and are not stirred. The following year finds the pile, somewhat compressed by snow and rain, at 2/3 of its previous height but not many leaves have broken down and consequently there is not much carbon dioxide release from this pile. At the bottom, an identical leaf pile has been stirred frequently- turning it provides opportunities to move bacteria into zones of fresh material to break down. Because of that, there is a lot more carbon dioxide release as this occurs. Note that the source of the extra carbon dioxide which diffuses from the bottom pile is the microbial transformation of the organic substrate- the leaves.

The carbon cycle

The carbon cycle (*right*) can be modeled as a balancing act between composing (top arrow) and decomposing (bottom arrow). Composing involves taking carbon dioxide from the atmosphere and composing it into sugars (cellulose and starch); and then decomposing this organic matter through the respiration of soil microbes turning them back into carbon dioxide. The rapid spinning of this cycle is what's favored by the bacteria. Soil organic matter increases when we favor the compose part of the cycle; intensive tillage (stirring) favors decomposition of soil organic matter. Different organic matter sources and qualities that are added to this process are going to affect it differently. As discussed in chapter 8, "Applying the Cornell Soil Health Test to Berry Production" living (and dying) soil organisms serve several functions to break down organic debris, to create/ release soil glues, to release nutrients, protect or infect crop plants, and serve as food for other organisms.



Cornell Soil health Test Indicators (review)

The wet **aggregate stability** test is an indicator for the soil organisms that create and release soil glues; this is accomplished through organic debris breakdown and their subsequent release of compounds which bind soil particles together. Dead roots of crops and cover crops can insert organic matter deep into the soil profile.

The **potentially mineralizable nitrogen** test is an indicator for the soil organisms that release nutrients. It measures the capacity of soil microbes to break down organic soil nitrogen into ammonium.

Soil organisms can protect or infect crop plants. The indicator for this soil health process is the **soil bioassay** using green bean seedlings. Once we have an idea of what micro-organisms are present we can manipulate our soil health management practices to either favor or disfavor them.

The **active carbon** or "kindling" of the soil organic matter is the easily accessible, easily oxidizable, easily available, easily digestible material in soil. This material provides energy to drive the soil biota through their diverse soil functional processes.

Soil management guidelines

Holistic soil management requires an understanding of soil processes. Soil health testing reveals the capacity of the soil to perform these functions using indicator tests. The soil health management strategy is then tweaked to address any of these identified soil performance constraints. Often a synergistic approach is possible whereby one management tactic may redress one or more constraints at the same time, saving effort and expenditure.

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	66.1	95	
	Available Water Capacity (m/m)	0.13	51	
	Surface Hardness (psi)	273	12	rooting, water transmission
	Subsurface Hardness (psi)	375	27	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	2.8	42	
	Active Carbon (ppm) [Permanganate Oxidizable]	365	21	Soil Biological Activity
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	8.0	25	N Supply Capacity
	Root Health Rating (1-9)	3.3	75	
CHEMICAL	pH (see Nutrient Analysis Report)	6.0	67	
	Extractable Phosphorus (see Nutrient Analysis Report)	4.5	100	
	Extractable Potassium (see Nutrient Analysis Report)	112.5	100	
	Minor Elements (see Nutrient Analysis Report)		100	
	OVERALL QUALITY SCORE (OUT OF 100):		59.6	Medium
	Soil Textural Class:==> sandy loam			
	SAND (%): 53.0	*SILT (%): 42.0*		*CLAY (%): 5.0*

To review from page 119, the **first step** is to take a look at soil health test results (*left*) and identify any constraints. This is the test results for a two-year old strawberry planting; it had a rye vetch cover the year before it was established; it's on a sandy loam soil.

If we look first at the physical soil characteristics, aggregate stability has a 95% rating, in the green, indicating a very nice soil structure. However, as we move down the list we see there is surface hardness and subsurface hardness so there's some compaction in the soil which will need to be taken into account as the grower moves forward. In the biological realm we see there's a decent amount of total organic matter present in the soil (42%); but the fresh organic material (active carbon) is low at 21% and the rate of mineralization of nitrogen (breakdown of organic material into available nutrients) is also low at 25%. Root health is relatively good at 75%.

Soil chemistry is good; soil pH is slightly low at just outside the desired range (6.2 to 6.5). Phosphorus and potassium levels are good, along with minor elements.

The overall score then is 59.6, in the medium range. Now the grower has the option to select some management practices to try on this field to see if they can address the indicated constraints. Once management practices are in place the grower would test again to see what effect these are having on soil health.

The **second step** is to brainstorm management options. Figure 46 lists potential practices that are seen as a starting point in the decision-making process of potential soil remediation practices.

Figure 46. *Suggested management strategies for addressing soil health constraints*

	Short term or intermittent	Long term
Physical Concerns		
Low aggregate stability	Fresh organic materials (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, surface mulch, rotation with sod crops
Low available water capacity	Stable organic materials (compost, crop residues high in lignin, biochar)	Reduced tillage, rotation with sod crops
High surface density	Limited mechanical soil loosening (e.g. strip tillage, aerators); shallow-rooted cover crops, bio-drilling, fresh organic matter	shallow-rooted cover/rotation crops; avoid traffic on wet soils; controlled traffic
High subsurface density	Targeted deep tillage (zone building, etc.); deep rooted cover crops	Avoid plows/disks that create pans; reduced equipment loads/traffic on wet soils
Biological Concerns		
Low organic matter content	Stable organic matter (compost, crop residues high in lignin, biochar); cover and rotation crops	Reduced tillage, rotation with sod crops
Low active carbon	Fresh organic matter (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, rotation
Low mineralizable N (Low PMN)	N-rich organic matter (leguminous cover crops, manure, green clippings)	Cover crops, manure, rotations with forage legume sod crop, reduced tillage
High root rot rating	Disease-suppressive cover crops, disease breaking rotations	Disease-suppressive cover crops, disease breaking rotations, IPM practices
Chemical concerns	*See also soil fertility recommendations*	
Unfavorable pH	Liming materials or acidifier (such as sulfur)	Repeated applications based on soil tests
Low P, K and Minor elements	Fertilizer, manure, compost, P-mining cover crops, mycorrhizae promotion	Application of P, K materials based on soil tests; increased application of sources of organic matter; reduced tillage
High salinity	Subsurface drainage and leaching	Reduced irrigation rates, low-salinity water source, water table management
High sodium content	Gypsum, subsurface drainage, and leaching	Reduced irrigation rates, water table management

As consultants and educators or growers, we must continue to learn of the latest technologies and principles available to accomplish field objectives. Differing commodities or production systems (organic vs conventional, bedded vs flat) require expertise to be shared between the consulting Ag professionals and the grower. How to deal with measured soil constraints has to be addressed on a CASE BY CASE, FIELD BY FIELD, GROWER BY GROWER basis. Examining the information provided requires considerable attention, thought, and creativity to be of the most value.

We have now added constraints (Step 1) and management options (Step 2) to the field management sheet. For management options we might propose the following (red arrows above): The grower first may want to identify/find the compaction layer(s); options to mitigate these might be to plow, rip, or use an appropriate cover crop to break them up. At the same time, the grower may want to feed the soil with a heavy debris, rich root residual (clover, vetch, or alfalfa), or disease suppressive cover crop (various brassicas) to get their bacterial cycle spinning a little faster to address active carbon and mineralizable nitrogen constraints.

Step 3 involves an assessment of equipment and labor that may be available to help mitigate the limiting factors, and understanding the history of the field to determine what might have contributed to its current condition. Which options are actually feasible to implement?

Step 4 is developing a satisfying and workable management plan using the Soil Health Management Toolbox.

Field Management Sheet

Step 1. Identify constraints

- Surface and subsurface compaction
- Low available energy for soil biology
- Low conversion rate to NH4

Step 2. List management options

- Find hard layer- plow, rip or use appropriate cover crop
- Feed soil with heavy debris, rich root residual, disease suppressive crop

Step 3. Determine site history/ farm background

Situational opportunities and limitations- site history, equipment availability, labor, field location

Step 4. Management Strategy

Adapt field management options to the capacities and needs of the grower

CORNELL SOIL HEALTH TEST REPORT

RyeVetch/ STW/STW
Sandy loam

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	66.1	95	
	Available Water Capacity (m/m)	0.13	51	
	Surface Hardness (psi)	273	12	rooting, water transmission
	Subsurface Hardness (psi)	375	27	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	2.8	42	
	Active Carbon (ppm) [Permanganate Oxidizable]	365	21	Soil Biological Activity
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	Root Health Rating (1-9)	3.3	75	
CHEMICAL	pH (see Nutrient Analysis Report)	6.0	67	
	Extractable Phosphorus (see Nutrient Analysis Report)	4.5	100	
	Extractable Potassium (see Nutrient Analysis Report)	112.5	100	
	Minor Elements (see Nutrient Analysis Report)		100	
	OVERALL QUALITY SCORE (OUT OF 100):	59.6	Medium	

Soil Textural Class:==> sandy loam

SAND (%): 53.0 *SILT (%): 42.0* *CLAY (%): 5.0*

The Soil Health Management Toolbox

1. Crop Rotation/ hybrid choice
2. Growing cover crops
3. Organic/ chemical amendments
4. Reducing or modifying tillage

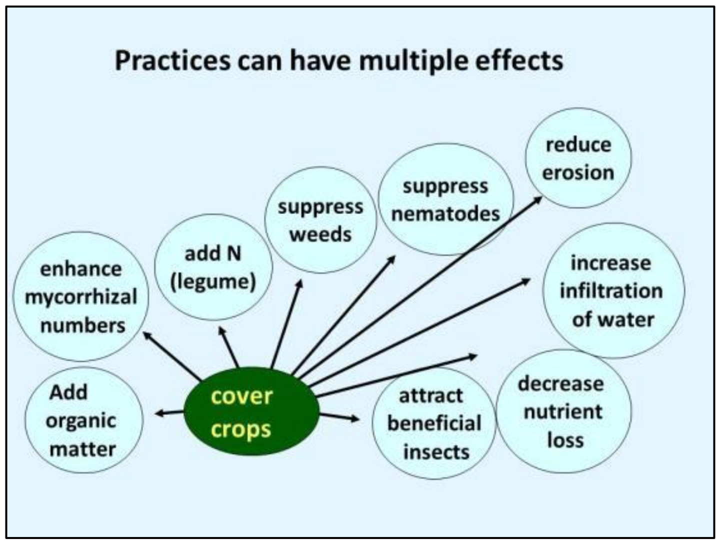
1. Crop rotation

Crop rotation is an agronomic approach to soil health management which brings to the table the ability of different plant types to suppress disease, to generally build organic matter and soil health, and smother weeds. It puts a different material there or not there at different times, affecting the soil biology.

Crop rotation is best used with shorter duration berry crops such as strawberries and raspberries. A minimum of a 3 year rotation out of strawberries and raspberries is recommended. Five years is preferable if there is sufficient land to allow for a longer rotation. Strawberries and raspberries share some soil-borne disease and insect susceptibilities with other crops. This is especially true for members of the solanaceous family, such as potatoes, tomatoes, peppers, eggplant and also for some forage crops, such as alfalfa. It is not a good idea to follow these crops with berries for a minimum of 3 years if at all possible. It is during these “off-berry” years that creative attention to crop rotation would be useful. Corn, beans and oats would be examples of crops that could be used in a berry crop rotation.

2. Cover crops

If land constraints prevent an adequate rotation time out of berries consider inserting a one or more cover crops into the sequence that has the capacity help mitigate multiple soil constraints at the same time. Other considerations with cover crops include selecting covers that best utilize land/equipment/labor and their ability to be sold in high return markets. The type of cover crop and the qualities it brings to the table in terms of soil health benefits is a major consideration. Another consideration is the timing of its use and how the cover crop may (or may not) fit into the management timetable as they fit in different windows: winter cover crops, summer fallow cover crops, season-long cover crops.



Deciding to grow a cover crop only puts the book on the table; it still needs to be opened and read. It’s a brave new world with a wealth of information out there which needs to be considered when making cover crop choices.

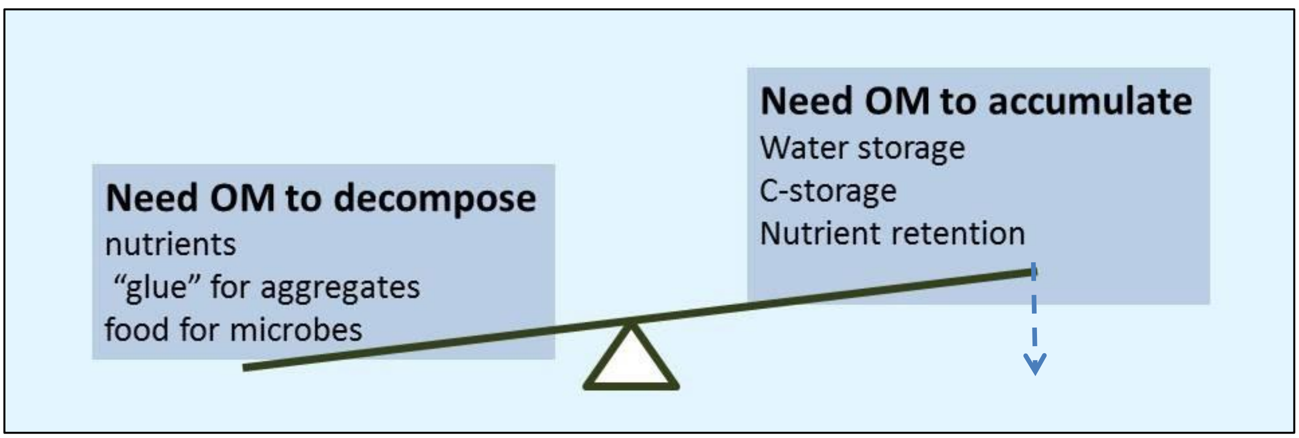
Note that each option tested in deciding on a particular strategy is always an iteration towards a final decision- does this work, how does this work? It can always be modified toward what is needed. “Success stories” of the use of different crop/ cover crop combinations from other growers are useful starting points. Growers can “start small” by trying strip trials or half of the field to learn how it will work on their farm before fully committing. Be aware and learn of possible new pest introductions with these new strategies. One needs to be vigilant and ready to learn whatever is necessary to move forward.

A list of potential cover crops for blueberry plantings is displayed in Appendix F. These specific cover crops will tolerate a lower soil pH which will be necessary in a blueberry site.

3. Organic/Chemical Amendments

In terms of amendments, manure and compost as useful candidates for application are deceptively easy to list but the diversity of manures, composts and green manures available and how best to use them require creative thought and decision making on the part of the grower. At the beginning of this chapter we discussed some of the dynamic processes to be considered in making good choices on compostition of added materials. We must apply a similar approach to understanding the cycles of breakdown and release of other additions like crop residues and biochar. Don't forget to include the effects of conventional amendments such as fertilizers, pesticides, and herbicides. These organic materials provide not just plant nutrients but active carbon and humic carbon for the soil biota to exploit.

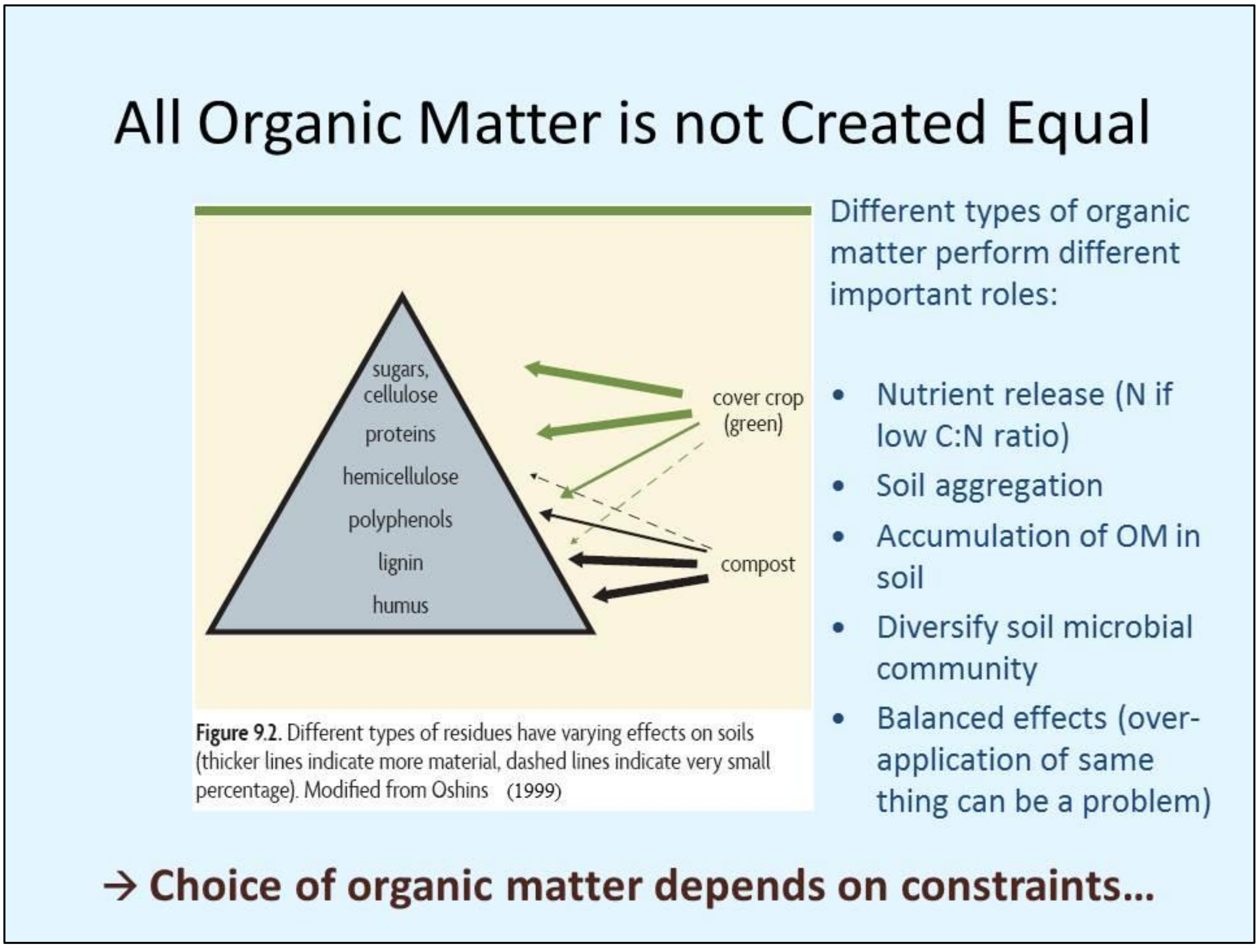
Managing soil organic matter is a balancing act. There is a need for organic matter to decompose in soil at the same time there is a need for organic matter to accumulate. As it decomposes it releases nutrients, "glues" soil aggregates together and feeds important soil biological processes. At the same time we also want organic matter to accumulate to store water, to retain nutrients, to loosen the soil and to store for carbon. The only way to achieve this balance is to literally keep growing and/or adding organic matter because as we decompose it we have less and less. We can only accumulate it by growing or adding more. Regular additions need to be made of diverse kinds of organic matter (manures, composts, cover crops, crop residues, leaves, biochar) to tip the scale the other way allowing us to accumulate on a gross basis even though at times we need to decompose organic matter. These regular and diversified additions also promote a broader base of organic activity in the field.



Organic matter losses through excessive decomposition and erosion need to be minimized and crops need to be rotated.

When we add green matter or green manure as a cover crop we are adding sugars, lighter, less complex compounds the bacteria are very hungry for. When we add composts we've moved further down the pyramid in the compost pile into these more complex longer lasting materials.

As portrayed in the schematic below, each of these materials will perform different important roles in the soil: nutrient release, soil aggregation, microbial community diversification, and balance. Buckwheat is an excellent example of a tender green manure crop which decomposes quickly and therefore can have a particularly profound effect on soil aggregation in a very short time.



More is not always better….

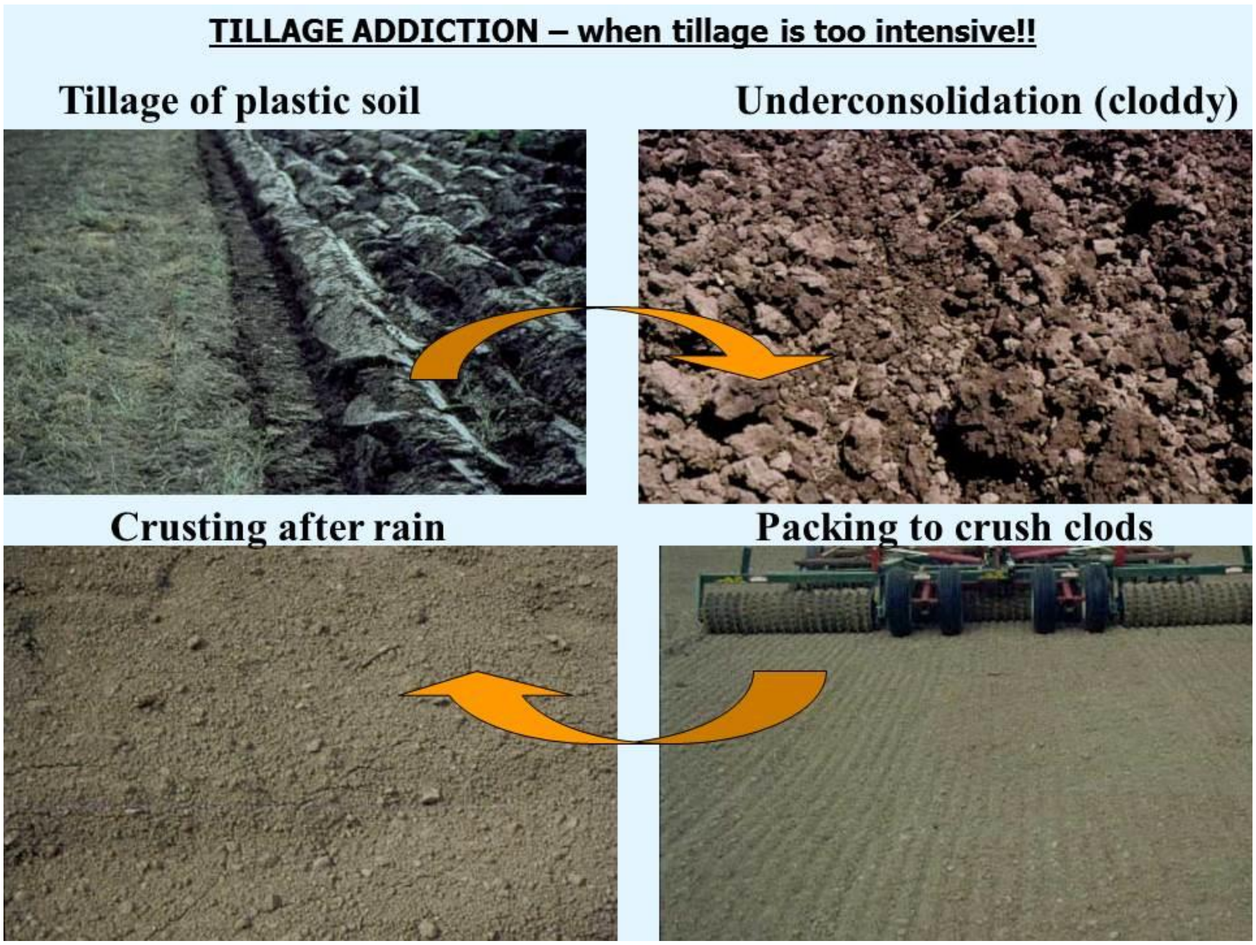
We have to be particularly careful when applying composts and manure as over-application may generate excess leaching and denitrification losses. In vegetables, too much vigor is undesirable. Excess vegetative vigor and reduced quality can result from too high a supply of soil nitrogen and/or other compounds and compost additions may keep soils too wet during period of fruit set. We need to start from a safe place and modify from there. Use organic application rates based on industry standards and modify after paying close attention to soil and plant response. Appendix B presents various conversions that allow for easier calculation rates.

4. Tillage

Tillage assists in breaking up hard soil layers, eliminating ruts caused from heavy traffic, burying residues and preventing compaction. New equipment can allow for innovations in disturbance by using different shapes of shanks, different shapes of coulters. Local wisdom often can be very useful for guidance in the best ways for remediating compaction.

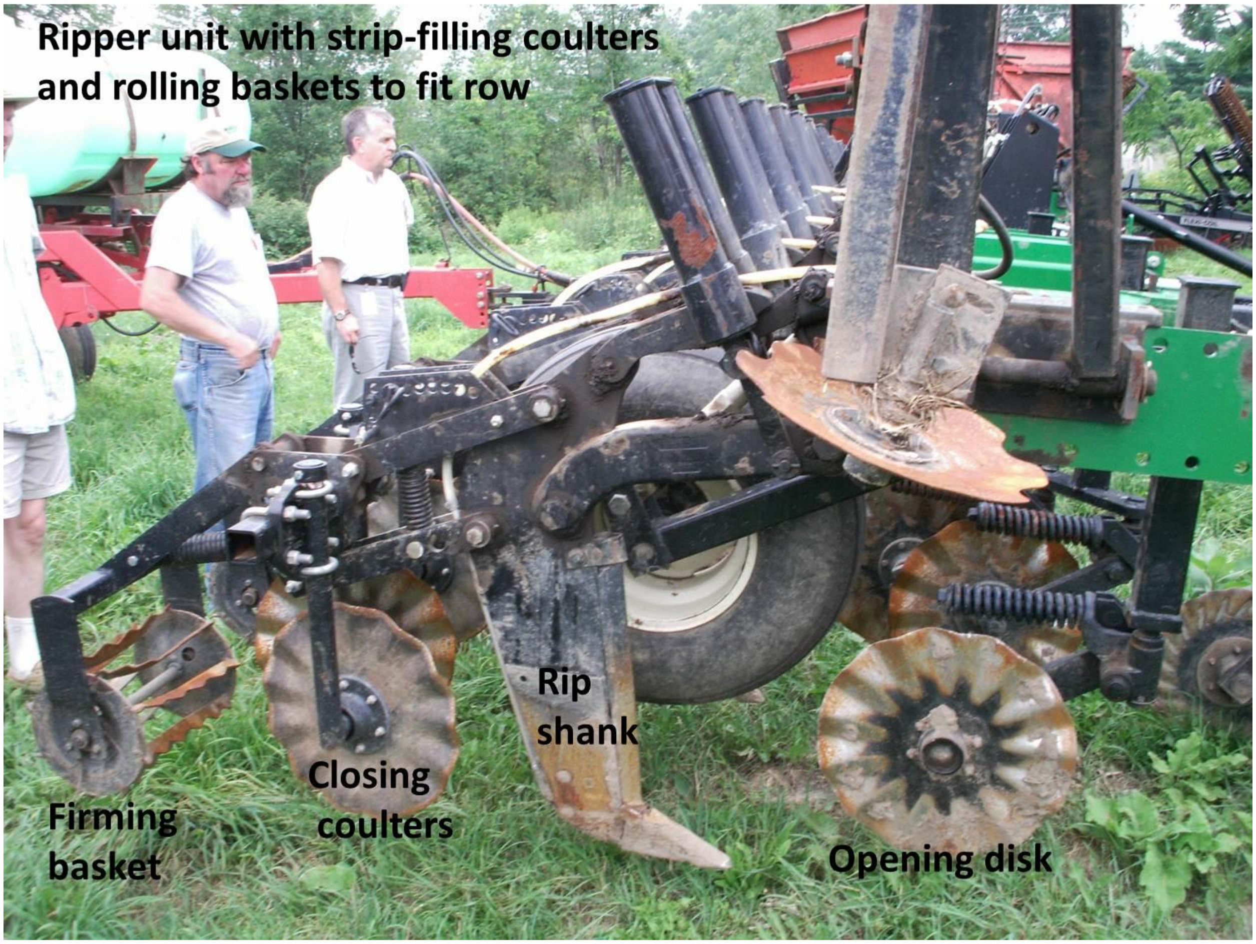
Tillage can also have some adverse effects, however, if used inappropriately or too intensively. Back to our leaf compost pile example offered above- remember stirring of the pile speeds up the bacterial biological processes (mineralization) and the way we do that often is with tillage. Intensive tillage literally results in “burning up” the current store of organic material as the soil biota is able to be mixed into new areas of available material to decompose it to carbon dioxide gas. Moderate amounts of this stirring coupled with timely additions of organic debris can be used to maintain the soil in a balanced condition.

In the top left photo of the photo montage below we see a soil being moldboard plowed a little too wet. Once the soil is flipped over the result is cloddy soil in the top right photo. This does not make for a good seed bed so then the soil is packed/firmed to crush the clods and make a more even surface (*lower right*). This in turn leaves the soil bare and unprotected, setting the soil up for potential crusting. (*lower left*). Admittedly this is a worst case scenario, but tillage is a powerful tool that should be respected in its capacity to degrade soil structure. Intensive tillage can severely affect soil processes, along with soil physical structure.

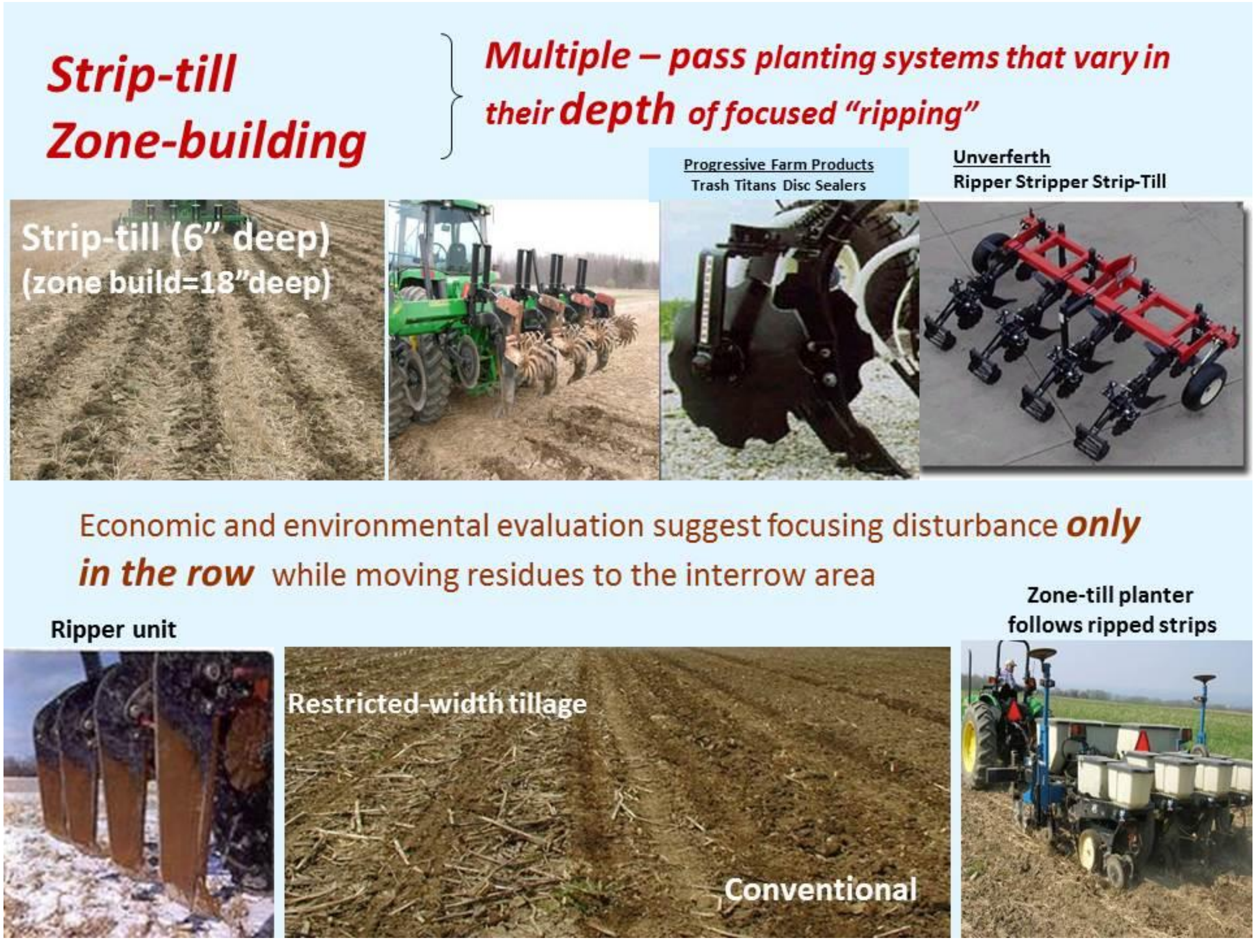


A newer strategy than the full width moldboard tillage in the scenario above is a more focused form of tillage. Shown below is a deep ripper tool which is capable of breaking up hard soil layers up to 18” deep. This one is set up for row crop production and has a rather narrow shank typically about 1 inch wide.

To take advantage of the capacity of the ripper to remediate compacted layers we first need to determine the depth in the field where the compacted soil occurs. A field penetrometer can be pushed into the ground when the soil is at field capacity. Soil layers having a resistance over 300 PSI are targeted for loosening. When the soil is friable down to that layer the tool can be set 2” deeper to break through the restrictive layer. A sod forming crop during or following the operation helps to maintain the looseness obtained.



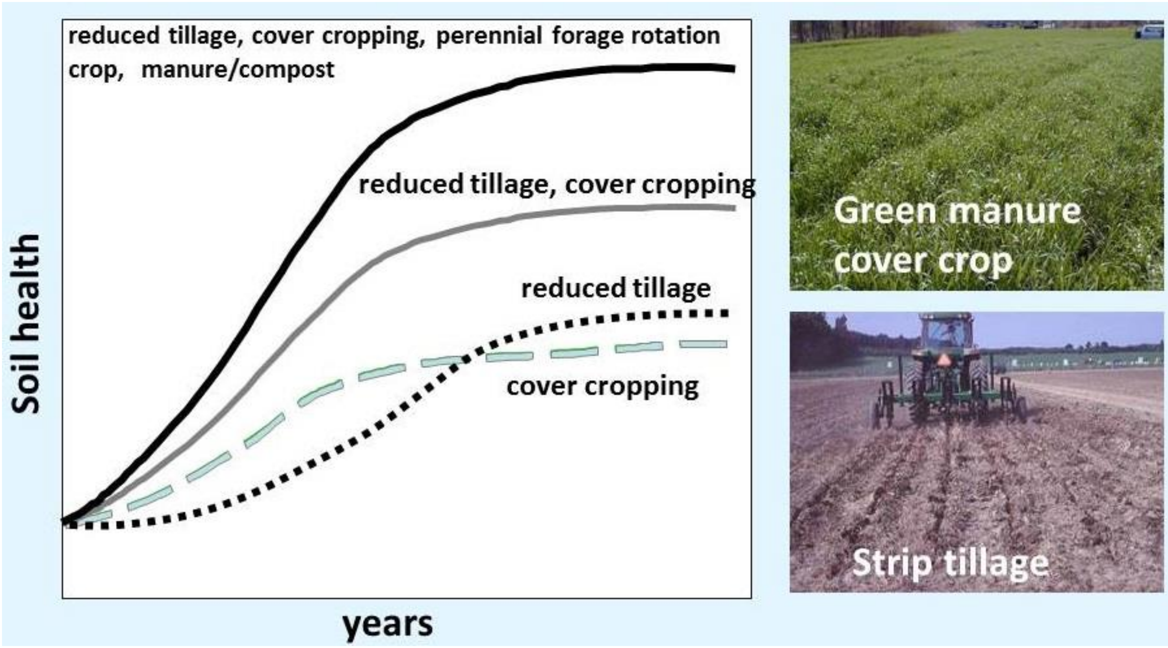
Another feature of this piece of equipment is to focus the tillage right in the vicinity of the rip shank rather than flipping the entire field surface over as in the mold board plow illustration above. This is pictured in the upper left photo in the illustration below-note for the most part there is an undisturbed surface. The rip shank can be set at variety of different depths, whatever is necessary to break up restricted layers, leaving a no-till environment between the rips and a tilled environment where the rips are. By focusing the disturbance we get the best of both worlds in this hybrid system- we plow just where the soil needs to be loosened for successful planting and young seedling growth but we leave the soil covered and undisturbed between the rows. If the weather turns hot and dry the soil surface does not completely dry out as in conventional tilled system. In the strip-till or zone-built tillage area the plant (in this case a row crop) has opportunity for moisture in the no-till zone between the ripped areas where more soil moisture is retained. An ideal time to loosen restrictive soil layers in berry crops is during fallow years in the rotation cycle. Combining this loosening to promote vigorous growth of a rotation crop builds the soil for the subsequent berry crop. Some growers may be interested in preparing ripped zones where the berry plants will be set while other growers may want to focus on the entire field area.



Tips for transitioning to reduced tillage crop production

- **Soil loosening** is the first step in alleviating any soil compaction ***SHORT TERM***
- Consider focusing tillage efforts on **specific zones**, looking to minimize stirring effect where not directly necessary
- When limited compaction has occurred, **zone building or strip tillage** will suffice
- Rebuild beneficial microbial communities by **feeding the soil food web**
- Soil structure is additionally improved through **cover crops, rotation, and fresh organic additions** ***LONGER TERM***
- Reduced tillage soils are less susceptible to compaction and more resilient due to better soil aggregation ***LONGER TERM***
- Healthier, balanced soils respond more favorably to reducing tillage

Combining the various management practices that promote soil health can have a synergistic effect. In the graph below we see soil health on the Y-axis and years on the X-axis. If we modify our management by finding windows for different cover crops or reducing our tillage, these individually applied management choices can increase our soil health. But if we can creatively put them together, and combine them with an overall holistic plan there tends to be a faster and greater overall response.

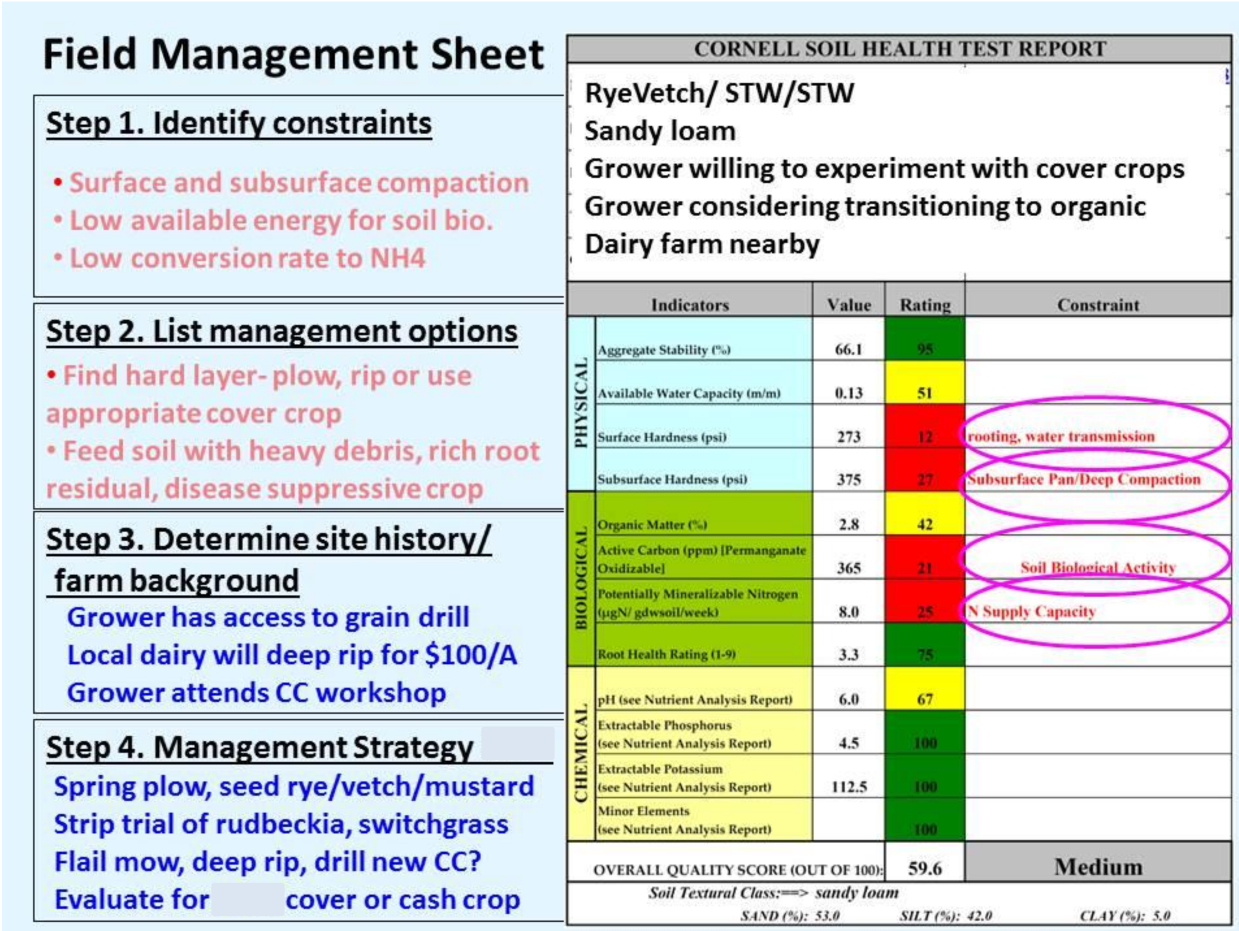


Finding Creative Solutions

In our example, a strategy might be to spring plow, lightly disk and then seed with a rye/vetch/mustard mix to get a sod-forming cover crop with the rye. The vetch will supply nitrogen, the mustard has a deep tap root and also releases some disease suppressive compounds. The grower also wants to try a strip trial of Rudbeckia and/or switch grass, which he learned in his cover crop class have good soil organics properties for strawberries. He will flail mow and then deep rip, leaving all of the residues on the field to add organic matter. He may consider drilling a new cover crop if one of these doesn't pan out. Then he will evaluate for next year whether he will continue this cover cropping or go to a cash crop like sweet corn.

Another example: Dairy farmers in Vermont were concerned about soil health on their corn lands. The colder continental climate of the state limits the time window for cover crop establishment before winter dormancy sets in. Working together with University of Vermont specialists, the farmers experimented with shorter-season corn varieties that mature seven to ten days earlier and increase the time window for cover crop establishment equivalently. They found their corn yields were generally unaffected by the shorter growing season, but their ability to establish a rye cover crop is greatly enhanced. In fields where high value market crops are grown, the years of the rotation with fallow crops have become ideal targets for the application of intensive remedial soil management. Larger equipment can be used to quickly manipulate the soil and seed rotation crops. Conventional wisdom suggests to start with strips and trial various strategies to arrive at cover crop and rotation crop combinations that fit best into a particular system.

Back to our strawberry example



Summary

A sound soil improvement and management plan should:

- √ Assess your soil's health to identify constraints
- √ Facilitate changes in management strategies that could work for your farm, and that address specific constraints
- √ Suggest creative experimenting on your farm to see what works in your situation… (start small)
- √ Adapt many resources of information to your farm
- √ Build healthy soils to increase resiliency to extremes

Additional Resources

1. Mohler, C.L., and Johnson, S.E. 2009 Crop Rotation on Organic Farms: A Planning Manual. PALS publication 117, Ithaca, NY. 154 pp. http://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms
2. Building Soils for Better Crops.
3. Managing Cover Crops Profitably, 3rd edition.
4. Cornell Cover Crop Decision Tool for Vegetable Growers. http://covercrops.cals.cornell.edu/decision-tool.php

Chapter 10 Environmental impacts of nutrient use – Runoff, leaching, Minimizing impacts, Management – *Dr. Harold van Es, Cornell University*

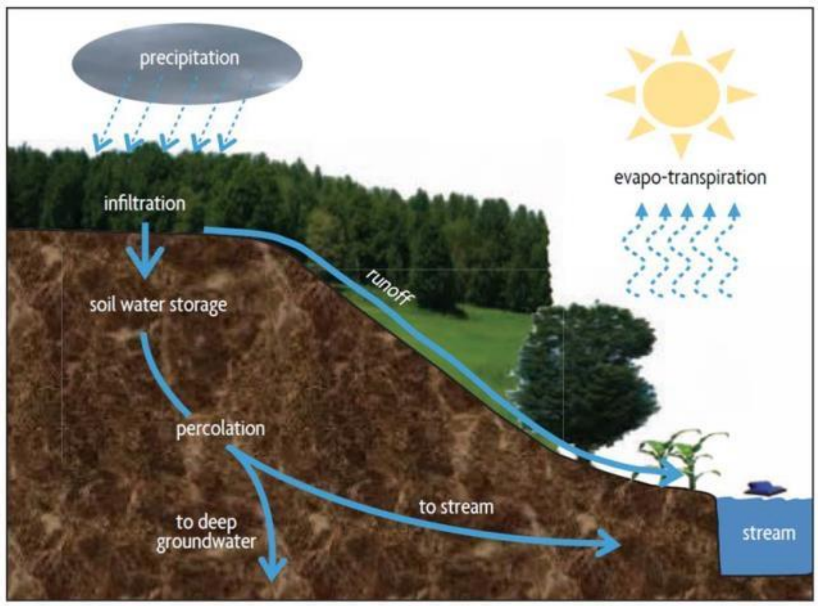
Introduction

It is important to note that most berry crop production is done in a way that is relatively sustainable and has relatively little environmental impact. Comparing berry crops with corn for example, we see most berries are produced on a smaller scale, are perennial vs. annual, require less nutrient inputs and less tillage. Their environmental impact is smaller then, yet still a matter of concern and something to be taken seriously.

Various soil components, when carried by excessive water events (i.e. precipitation) into water bodies, become contaminants, potentially causing serious damage to the ecosystems they enter. These are referred to as environmental losses. The 4 primary environmental losses to be concerned about with berry crop production are sediment, nitrogen, phosphorus and pesticides.

Environmental loss processes

Environmental losses occur when there is a lot of water in the soil system; this water comes mostly as precipitation and irrigation. That said it's the extreme precipitation events (1 to 2" or more of water at a time) that cause environmental losses to occur.



The basic hydrologic cycle

So what happens to precipitation when it reaches the land's surface? It basically goes in two directions (*right*). The water either infiltrates into soil or runs off. Water that runs off often takes sediment with it; this process is referred to as erosion. Soil nitrogen and/or phosphorus may also be carried off at the same time. These soil components, now contaminants, may then readily reach streams, lakes estuaries or other bodies of water where they cause problems.

If all the water infiltrates it is then held by the soil "sponge" and made available to plants through evapotranspiration. If there is excess water in the soil sponge it percolates further down either as shallower or deeper ground water. Shallow ground water may eventually reach a stream or other body of water. Chemicals may be carried off in the percolating water, a process referred to as leaching.

So to summarize, the environmental loss pathways discussed thus far include runoff (nitrogen, phosphorus, pesticides), erosion (all four contaminants), and leaching (nitrate and pesticides).

A fourth environmental loss process is that of gaseous losses which involve nitrous oxide and pesticides. Gaseous losses which involve nitrous oxide (denitrification) are not directly driven by water but are indirectly water driven.

When the soil becomes anaerobic (without air), nitrate is transformed to nitrous oxide, a greenhouse gas 300 times more potent than carbon dioxide.

Gaseous losses of pesticides are not water related. Instead these are related directly to the properties of the pesticide itself. Pesticide losses will not be discussed further as it is beyond the scope of this chapter.

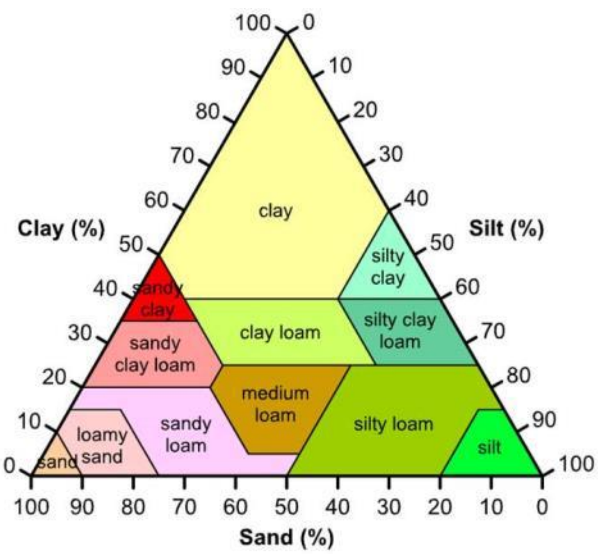
Environmental loss potential

The potential for environmental losses is affected by several factors; the first of these being weather. Intensive rainfall events bring with them higher potential for erosion; excess water also generates leaching.

Secondarily, inherent soil properties such as soil texture, organic matter and so on, affect where the water goes, and what it takes with it. This factor will be discussed in more detail later in the chapter. Thirdly, soil health is a factor. If soil health has been built up to where the soil has good aggregation, then environmental loss can be reduced significantly.

Finally, "real-time" soil management practices such as cultivation, soil cover, traffic, organic and inorganic fertilizer applications are also factors. Cultivation of soil exposes it to the elements, facilitating erosion. Soil cover, like mulch, reduces soil exposure and thus erosion. High traffic on soils causes compaction; this in turn leads to poor infiltration and runoff. Last but not least the amount of fertilizer applied, whether organic or inorganic, and where we place it is a significant factor. In principle, the more fertilizer applied the higher potential for losses.

Inherent properties of soil and how they affect the potential for environmental losses



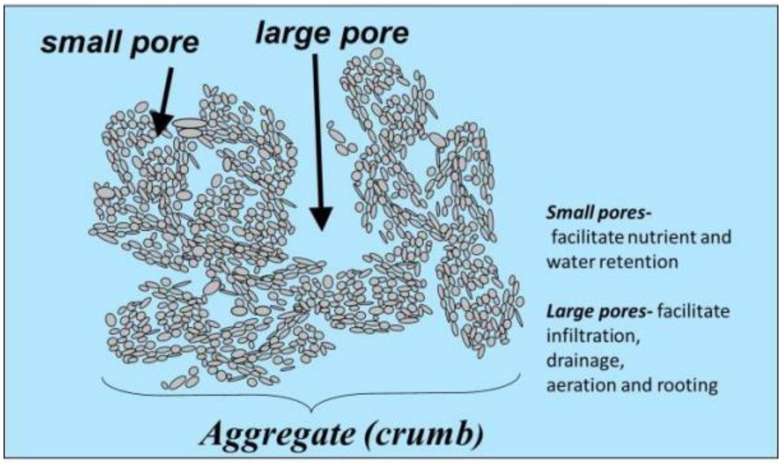
Soil texture or the distribution of soil particle sizes, in terms of sand, silt and clay, is the most fundamental inherent soil property. The textural triangle (*left*) provides the basis for a lot of these environmental loss considerations.

Soil particles and pores (texture) defines the basic structure of soil, what may be referred to as the soil "house". The structure of the house (walls, roof, and basement) comprises the most visible part of the house; in the soil these are the soil particles, or taken together, the soil aggregates or crumbs.

This is not necessarily the most interesting part of the soil house however, it's what happens in the soil spaces or "rooms" between the soil crumbs. These spaces are the soil pores where all of the processes take place (water and air movement), and where the organisms (bacteria, fungi) are, where the life is.

The relative quantity of the various sized pores — large, medium, small, very small — govern the important processes of water and air movement. In a sandy soil, most of the "rooms" or pores are relatively large (but in general terms still relatively small, less than 2 mm in most cases). These large pores (in terms of soil) will lose their water very quickly due to their weak capillary force. Conversely, clay soils mostly have small pores that retain water tightly (strong capillary force). If the clay soil is well-aggregated, it will have a few large pores in addition to the small ones. Figure 47 depicts an example of a soil aggregate or crumb with a range of pore sizes and their associated processes. Large pores facilitate infiltration, drainage, aeration and rooting. Small pores, because of their strong capillary force, facilitate both nutrient and water retention. So for example, when the concern is leaching, it's good to have small pores that retain nutrients in the soil.

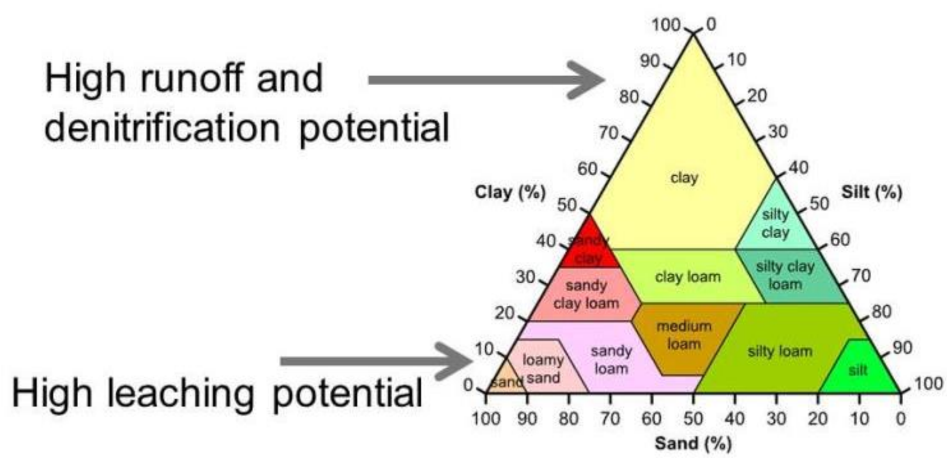
Figure 47. *Pore sizes and their associated processes.*



Quiz Yourself

1. Which soil has a higher leaching potential?
   a. Sand
   b. Silt
   c. Clay
2. Which soil has higher runoff and denitrification potential (gaseous losses of N)?
   a. Sand
   b. Silt
   c. Clay

Let's take another look at the textural triangle then in terms of loss potential. The more sandy soils i.e. sand, loamy sandy, sandy loam, sandy clay loam, etc. have higher leaching potential. The more clay soils i.e. clay, clay loam, silty clay, silty clay loam, etc. have higher runoff and denitrification potential.



Answers: Sand has the highest leaching potential because it has large pores that don't retain water and nutrients well; nutrients are easily washed out with the percolating water. A clay soil has the highest runoff potential with its small pores and lower infiltration capacity. Because clays are composed chiefly of small pores, aeration can often become a problem under excessive water conditions, causing denitrification (release of nitrous oxide).

Hydrologically sensitive areas, their characteristics and identification

Hydrologically sensitive areas are parts of the landscape that have high potential for pollutant losses. These areas are potentially sensitive to either surface runoff or leaching and subsurface recharge losses.

Potentially sensitive areas for surface runoff losses include flood plains, areas adjacent to flowing and standing water bodies, and areas with low infiltration capacity and saturated areas.

Most flood plains tend to have relatively coarse textured soils like gravels or sandy soils; these we would say have high infiltration capacity *but* because they are located near streams where heavy rains cause flooding they are sensitive to surface runoff and in this case, everything goes.

Similarly, areas adjacent to flowing or standing water tend to be hydrologically sensitive, as they tend to be wetter areas in the landscape and close to these water bodies; there is very little capacity for buffering or filtering out some of these contaminants in these adjacent areas.

Areas with low infiltration capacity are also a concern because the field soil itself has become compacted or the field is adjacent to another compacted area (i.e. road) where the runoff from this area causes runoff and erosion in the field. Saturated areas are already wet and so are subject to runoff as well.

Potential sensitive areas for leaching and subsurface recharge include: groundwater recharge areas near wells or springs and areas with permeable soils.

Groundwater recharge areas near wells or springs are areas that typically have very permeable soils; when you are close to these drinking water sources you need to be extra careful about minimizing/eliminating environmental losses in these areas. Other areas of very permeable soils are also of concern.

Soil survey reports, whether traditional map resources or on line resources such as the Web Soil Survey discussed in chapter 1, are valuable tools in identifying potentially hydrologically sensitive areas. They provide information on basic soil properties, suitability for use and environmental loss potential (runoff, erosion, leaching). The reports provide an excellent first look for evaluating this potential.

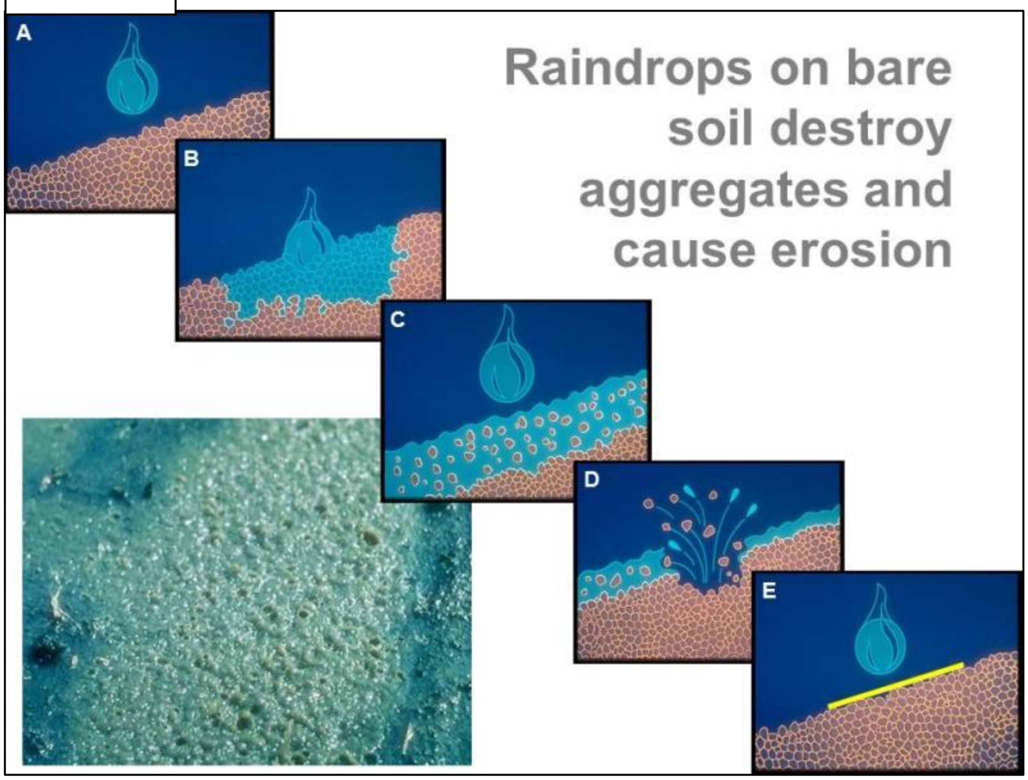
Erosion

Erosion has a 2-fold effect on the landscape. First, it removes surface soil which is highest in organic matter and most desirable for plant culture. What are left behind are the coarse gravelly fragments that are not as easily washed off by the runoff water (*above right*). The other effect of erosion is that the sediment that is washed away ends up somewhere else (*below right*), covering aquatic habitat, making water less potable (suitable for drinking) or les suitable for navigation. Both of these effects are highly undesirable; erosion remains a large problem in the United States.

A number of factors effect erosion including soil type, slope, soil health, and surface management. Soil textures with high runoff potential also have high erosion potential. Steeper slopes of course are of greater concern being subject to higher levels of erosion.

Soil health is another factor. If the soil is well aggregated, with good rooting that pumps the water out well, erosion potential is reduced. Surface management is yet another factor; whether the surface is kept covered, or exposed, the tillage methods used, herbicide use, all have a great influence on erosion potential.

Figure 48

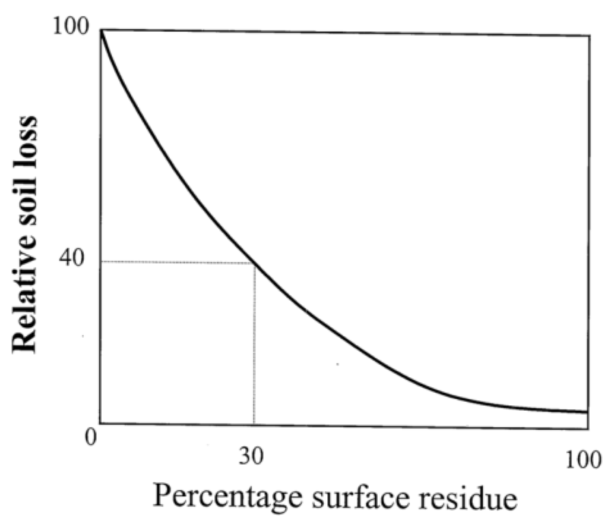


A falling raindrop has energy from its mass and velocity (*Figure 48a*). When it contacts a dry soil; the soil is hard and resilient and capable of absorbing the energy from that rain drop (*Figure 48b*).

As the soil begins to wet up it becomes softer and weaker. The raindrop energy cannot be absorbed as well; causing aggregates to be smashed and dispersed (*Figure 48c*). On a very soft soil you can actually see the impact of the raindrops (*Figure 48d and photo bottom left*). Water begins to accumulate at the surface and if the soil is on even a moderate slope you begin to initiate runoff and erosion.

Alternatively, raindrop energy maybe absorbed by a soil surface cover (*Figure 48e, represented by yellow line*) such as mulch, compost or other organic products which greatly reducing erosion potential.

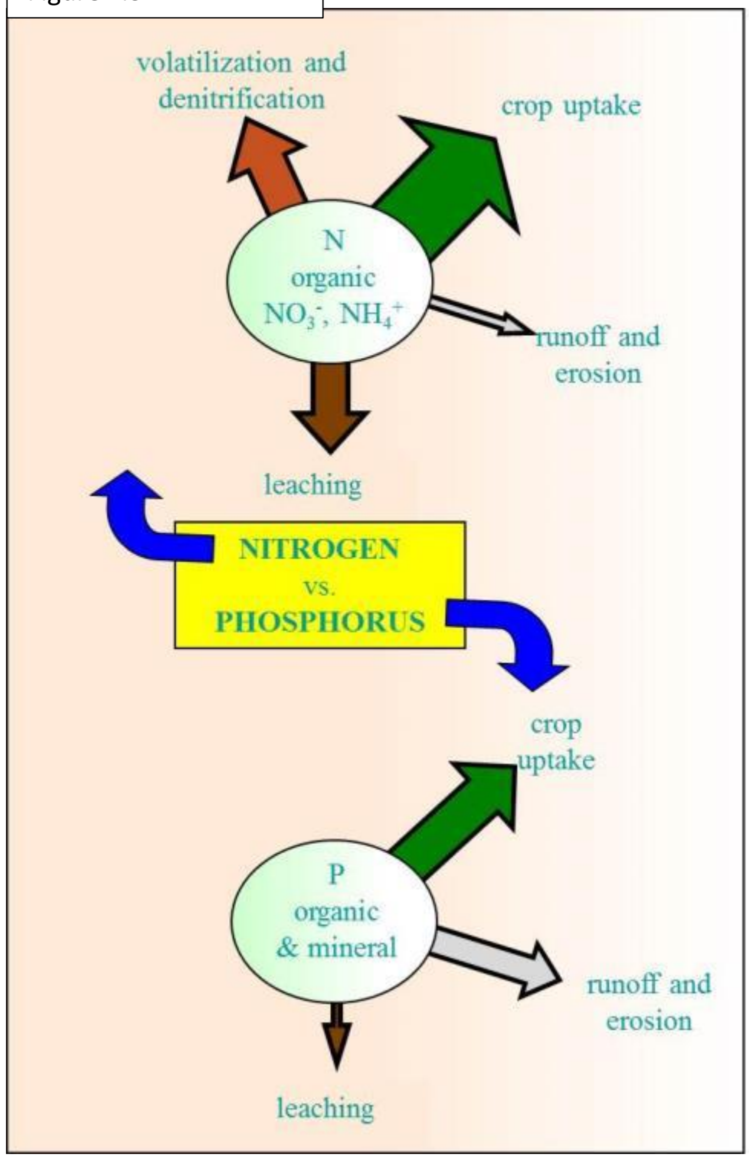
The rather famous graph on the right shows erosion (relative soil loss) from zero to one hundred percent vs the percentage of surface residue.



If the soil is bare, the relative soil loss is 100%. That said there is a fairly rapid decrease of erosion losses with even modest amounts of surface residue. Thus with 30% surface residue, the relative soil loss is reduced about 60% from 100 to about 40. As you approach 100% surface residue erosions losses become minimal.

The best way to reduce erosion is to have the soil covered. The good news is that this management practice also has a lot of benefits in terms of building healthy soils, reducing the effects of extreme water and temperature conditions at the surface, and promoting biological activity. To some extent then, it's a no-brainer to put mulch or some other organic material on the soil surface.

Figure 49



Erosion and runoff prevention

The main strategies then to avoid erosion and runoff then are 4-fold. First, if at all possible avoid fields that are prone to flooding or have high runoff potential. Second, keep soil covered with mulch, compost or crop residue as much as possible. Third, build and maintain soil health (aggregation, etc.) to increase infiltration capacity and reduce runoff potential. And finally, use grass alleyways between rows, preferably along the contour; this will infiltrate water quite well and filter out any sediment coming from the rows if they are unprotected. These practices are not difficult to implement and in fact are already in use by most berry growers.

Nutrient losses

The nine essential macronutrients for plants were discussed in previous chapters. By way of review, the first three of these, carbon, hydrogen and oxygen, are plentiful in the environment. Of the remaining six, nitrogen and phosphorus are the macronutrients that are applied in large quantities and are also of environmental concern. These two will be the focus of our discussion of environmental losses of nutrients.

The pictograph on the right shows different pathways for soil losses of nitrogen (*top*) and phosphorus (*bottom*); relative amounts lost are indicated by width of arrows.

Although N and P are both nutrients, they behave very differently in the soil and they have very different impacts. Each one will be discussed in more detail.

Nitrogen can be in the soil in both organic and inorganic forms as nitrate and ammonium. Most of the nitrogen present we hope will be taken up by the crop, promoting good growth; that's the objective. Nitrogen may run off or erode but typically these are relatively insignificant loss pathways; volatilization and denitrification are the primary loss pathways for nitrogen. Both of these processes are initiated by very wet soil conditions.

Phosphorus, on the other hand, can be in the soil in organic or mineral form. Again the desired pathway of phosphorus in the soil is crop uptake of course. Leaching is only a problem in some very rare cases where there are excessive amounts of phosphorus in the soil, in combination with sandy soils and very shallow water tables. In most cases, runoff and erosion are the primary loss pathways for phosphorus.

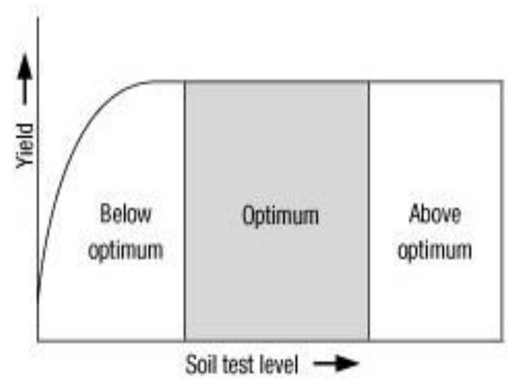
Managing phosphorus for reduced losses

Look again at the bottom half of the pictogram above, which focuses on phosphorus loss pathways. Primarily runoff and erosion are the concerns here.

Phosphorus, as we have learned, is a necessary nutrient for plants to live; it is also a limiting factor for aquatic plant growth in many freshwater ecosystems. Most fresh water lakes in North America are phosphorus limited. It actually takes relatively little phosphorus to induce eutrophication, a situation where excessive aquatic plant growth and decay occurs. Eutrophication is a natural process to some extent accelerated by phosphorus entering water systems form farms. Eutrophication favors growth of algae and phytoplankton over the more complex aquatic plants. As the algae die they sink to the bottom where they are decomposed by bacteria. This decomposition process uses oxygen; depriving deeper waters of oxygen, sometimes killing fish and other organisms. Moreover, eutrophication decreases the value of lakes and rivers for aesthetic enjoyment; health issues may ensure where eutrophication causes complications with drinking water treatment.

The photo at the right shows a Canadian lake with a barrier in between; one side of the lake received phosphorus inputs, the other side did not.

Berry farms are not likely a huge contributor to this problem but they could contribute as a consequence of poor management practices.



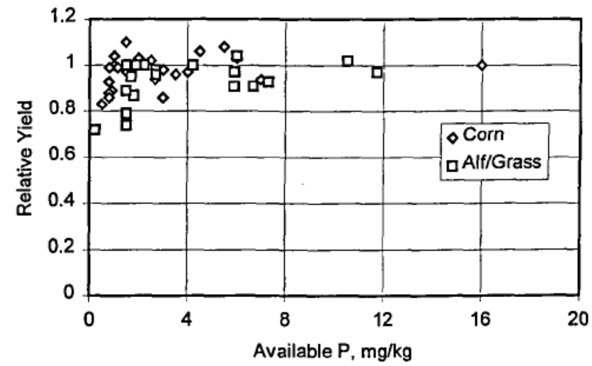
Practices that reduce runoff and erosion also reduce phosphorus losses also; things like surface mulches and improved infiltration capacity through good soil health management, etc.

There is another dimension to this however, basically, the accumulation of phosphorus in the soil. Lots and lots of phosphorus in soil increases loss potential, an additional concern.

Soil tests and phosphorus

Chemical extraction of nutrients provides a general estimate of crop nutrient availability; generally these estimates are low precision, but ranges of deficiencies and excesses are well defined.

This hypothetical graph gives us an idea of what happens to yield as phosphorus in soil increases (*top right*). In terms of soil tests, where we measure soil phosphorus on a regular basis, we know where phosphorus is very low, reduction in yield occurs and there is benefit to phosphorus addition. There is a point where there is sufficient phosphorus in the soil for good crop production; an optimum range where little if any additional benefit is realized from P input. Above that optimal range is excess, where not only are no additional benefits realized from inputs, but also there is cause for concern in regard to phosphorus loss through runoff and erosion.



The bottom graph provides real data on the relationship between relative yield and amount of available soil P for corn and alfalfa/grass. Looking at the data, for Morgan extractable P, in the range from 4 to 6 is about where the cut-off is for going from below optimum to optimum; there's no yield increase beyond that. And again at some point beyond 6 you reach excess levels.

Although the response to P levels is often quite variable and low precision, there is really strong agreement that there is a soil P level that is sufficient, not deficient, and not excessive.

The use of different chemical extractants gives slightly different results in terms of phosphorus extraction (*right*). Some extract a little bit more, some extract a little bit less, depending on the method used. It follows then that each extractant has its own set of ranges for low, optimum, high and very high. It's the very high range where we need to be concerned about excessive phosphorus. We want to keep these very high levels from happening in soil as much as possible.

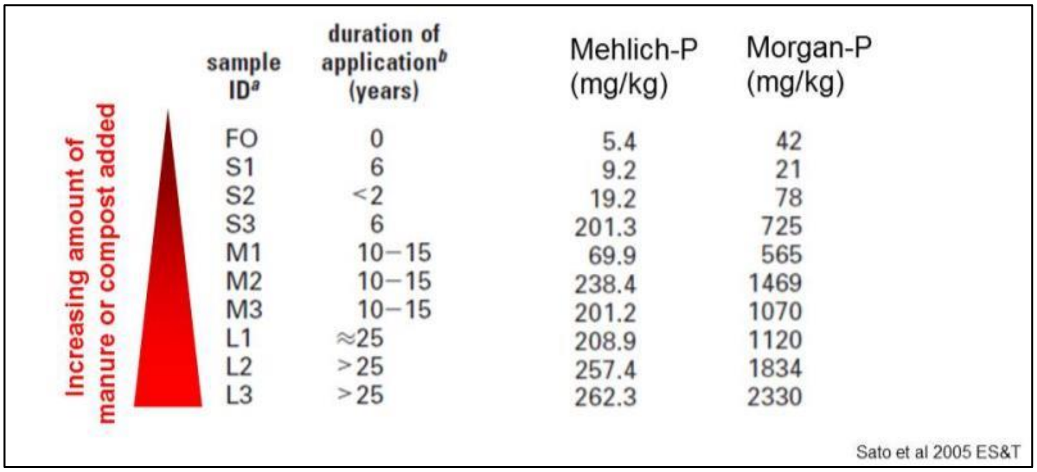
Interpretation Ranges for Different P Soil Tests

	Low	Optimum	High	Very High
Olsen	0–7	7–15	15–21	>21
Morgan	0–4	4–7	7–20	>20
Bray 1 (Bray P-1)	0–15	15–24	24–31	>31
Mehlich 1	0–25	25–50		>50
Mehlich 3	0–15	15–31	24–31	>31
AB-DTPA (for irrigated crops)	0–7	8–11	12–15	>15

Note: Units are in parts per million phosphorus (ppm P), and ranges used for recommendations may vary from state to state.

In most cases, if a grower regularly soil tests and is careful about how much they apply, problems of this nature generally do not occur. Cases were these excessively high levels do occur are those where a lot of organic inputs have been made. This is sometimes the case with manures, on dairy farms for example, with repeated applications causing P build up in soil. Another instance of this is on organic farms with repeated applications of compost. Both manures and composts are not as well-balanced in terms of nitrogen and phosphorus; that is, you typically apply too much phosphorus for what the crop needs when you apply the right amount of needed nitrogen. When this scenario plays out year after year, significant buildup of phosphorus levels can occur. *Figure 49* provides real life examples and test results below showing how phosphorus can accumulate with repeated applications of compost or manure.

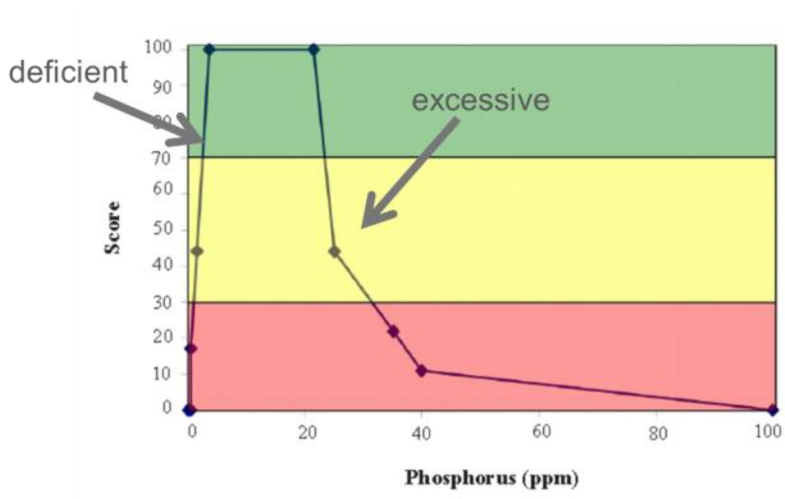
Figure 49. *Accumulation of phosphorus in soils with organic matter additions.*



sample ID[a]	duration of application[b] (years)	Mehlich-P (mg/kg)	Morgan-P (mg/kg)
FO	0	5.4	42
S1	6	9.2	21
S2	<2	19.2	78
S3	6	201.3	725
M1	10−15	69.9	565
M2	10−15	238.4	1469
M3	10−15	201.2	1070
L1	≈25	208.9	1120
L2	>25	257.4	1834
L3	>25	262.3	2330

Sato et al 2005 ES&T

Once an excessive level as soil phosphorus has been reached then you need to change your soil "diet" or how you add nitrogen to the soil. You might add clover or alfalfa residue, for example, if you are an organic grower of if not, a nitrogen fertilizer and smaller amount of compost to start reducing those phosphorus levels in soil.



The Cornell soil health test accounts for this in terms of the scoring curve used for phosphorus analysis (*left*). The actual value of a soil health indicator, phosphorus, is interpreted on a scale from 0 to 100. Very low P levels receive a low score; as P increases the score increases as well. Four to six is the optimal level; then it is down-scored as levels reach excess.

To summarize, there are 5 main strategies for reducing phosphorus losses. The first four are the same as those for minimizing runoff and erosion prevention. These include: avoid locations with high flooding or runoff potentials; keep soil covered with mulch or residue; build and maintain soil health (aggregation, etc.) to increase infiltration capacity and reduce runoff potential, and maintain grass alleyways (preferable along contour). The fifth additional strategy is to monitor soil P levels and use management practices that help to avoid reaching excessive phosphorus levels in soil.

These five management strategies are very effective for reducing phosphorus losses from soil.

Managing nitrogen for reduced losses

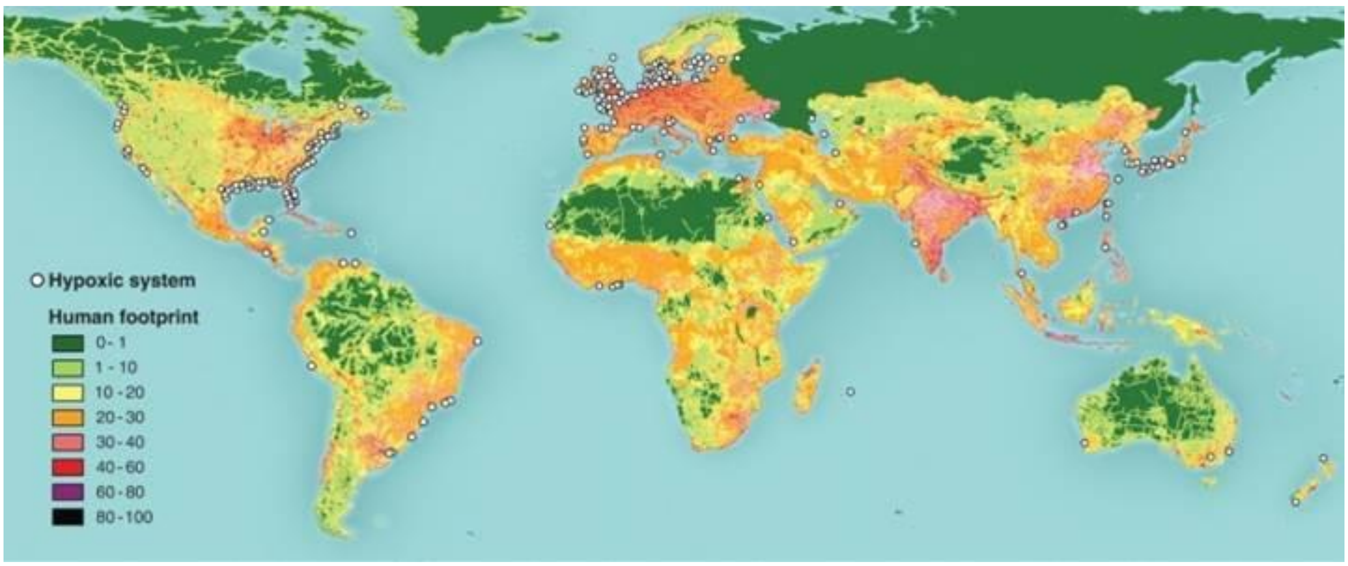
Nitrogen is a very complex element in the soil, both in terms of how it behaves in soil and also in terms of the larger considerations around nitrogen. There are currently a number of concerns in regard to nitrogen.

The first concern is the high energy consumption for the Haber-Bosch industrial process that takes atmospheric nitrogen to reactive nitrogen. It requires a lot of natural gas, a lot of energy, and generates a lot of carbon dioxide.

Secondly there is a persisting concern about ground water nitrate levels. There hasn't really been any improvement in general in these levels over the past couple of decades. This lack of improvement results in large part from over application of nitrogen, particularly in sandy locations, even urban areas (i.e. lawns, golf courses, etc.)

A third concern is the loss of nitrogen into rivers and streams and then into estuaries causing hypoxia/anoxia (low oxygen levels resulting in fish kill). Figure 50 below shows about 300 locations around the world where there are concerns with high levels of nitrogen in estuaries causing hypoxia/anoxia (low oxygen levels/fish kill). One area where this is well known in Northwestern Europe where there is a lot of nitrogen use, a lot of intensive dairying. This are is the original area where dairying was developed.

Figure 50. *The nitrogen problem (from: Diaz and Rosenberg, 2008)*



In North America, the area along the east coast from southern New England down to Florida and then along the Gulf coast where we have probably the largest problem with all of the nitrogen that comes out of the Mississippi river basin. This nitrogen is associated primarily with corn production.

These are often very important estuaries, for example the Peconic Bay on Long Island, where there are a lot of concerns, even from horticultural farms about trying to reduce nitrogen losses.

The fourth area of concern is greenhouse gases. Nitrous oxide (N_2O) is the result of denitrification. Again, berry crop production may not be a huge contributor but agriculture overall has a very large foot print in terms of greenhouse gas impact; actually very disproportionate to the share of the gross national product. About 7 to 8% of greenhouse gases are associated with agriculture; most of that is nitrous oxide losses. Nitrous oxide is about 300 times more potent than carbon dioxide. This needs to be reduced as much as possible through prudent and judicious nitrogen management.

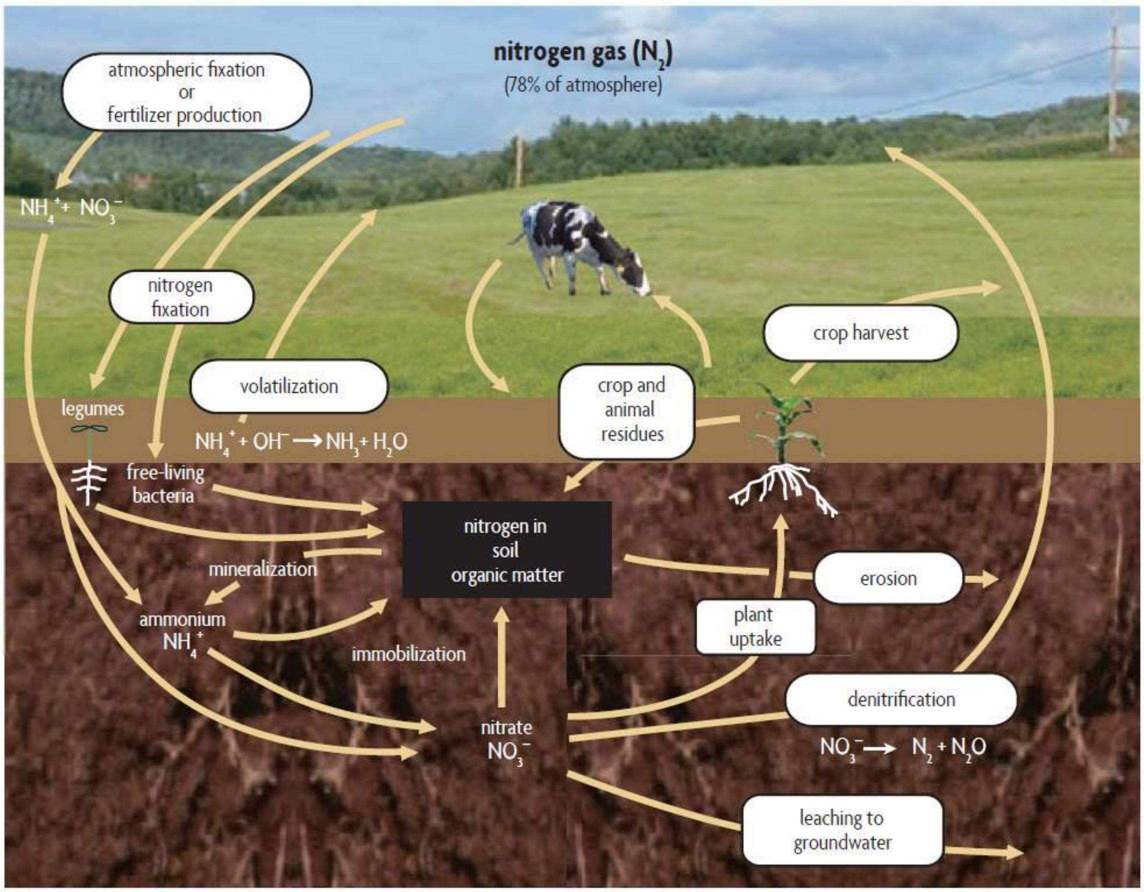
The nitrogen pathway

Returning to our previous pictogram showing pathways for nitrogen and phosphorus losses from soils, we see again crop uptake is the most desirable pathway. Some small amount of loss may occur through erosion but most of the losses will be leaching or denitrification. Leaching losses will occur on a more sandy gravelly soil as nitrate.

Nitrate is negatively charged and the soil is negatively charged as well; causing nitrate to easily percolate down and out of soil. Volatilization and denitrification losses are the nitrogen gas in the atmosphere (N2) which is not at all a concern because 78% of the atmosphere is already di-nitrogen gas. It's primarily the nitrous oxide that's the concern. When a denitrification event occurs, say from a heavy rain event (1 ½" or more), 30 to 40 pounds of nitrogen per acre may easily be lost either through denitrification or leaching.

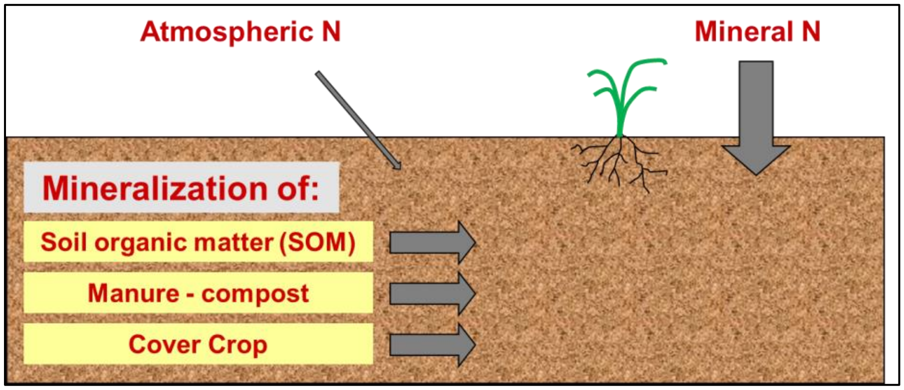
Volatilization of ammonia is the second component in this equation; it is primarily a concern with acidification.

The nitrogen cycle is relatively complex (*below*); we will not go into it in great detail here. Suffice to say a lot of these transformations that occur in the soil are driven in part by all these sources of nitrogen that come from agriculture. When nitrogen moves from one state to another state it may become subject to leaching or denitrification and gaseous losses.



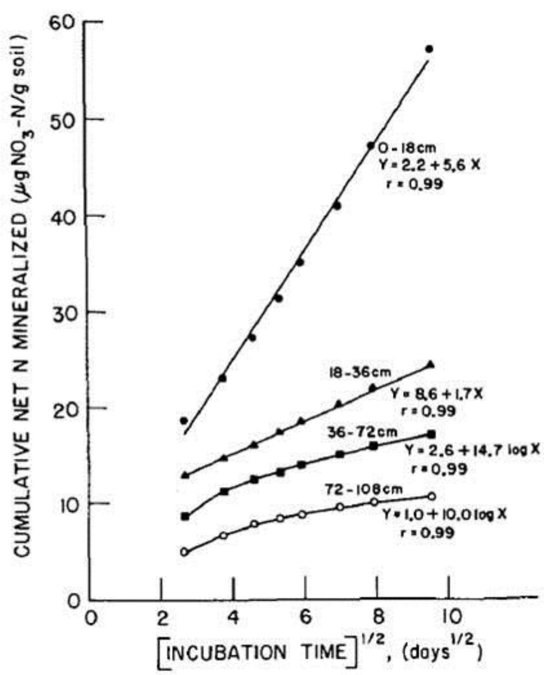
Nitrogen sources

A simplified chart below shows the sources of soil nitrogen. The first source of soil nitrogen is from the atmosphere; typically 6 to 8 pounds per acre; this is free nitrogen, but a relatively small quantity. In most field conditions we get a significant amount of nitrogen from the mineralization (decomposition) of soil organic matter occurring natively in the soil, applied as manure, compost, or residues, or as leguminous cover crops like clover or alfalfa. These get decomposed and the resulting organic nitrogen is mineralized to inorganic nitrogen primarily through biological processes which are in turn affected by temperature. The other source of nitrogen is mineral nitrogen, which is fertilizer, ammonium type fertilizers or nitrate type fertilizers.



There are many sources of variation associated with nitrogen availability, making it a little bit more difficult to manage nitrogen. Different soil types have different sources. If you are looking at Midwestern soils they have a lot of organic matter, are very deep, have good structure. They provide a lot more nitrogen in comparison to a podzol soil in the northeast that is very sandy and has relatively very little organic matter and nitrogen mineralization.

The amount of organic matter in the soil affects nitrogen availability. Soils build up organic matter when they are very well managed; they lose organic matter when they have a history of intensive tillage and/or erosion. How much you add in addition to "native" soil organic matter through application of organic amendments (manure, compost, etc.) , and whether you have cover crops and the types of cover crops you have (leguminous vs. grass covers) affects nitrogen availability. Soil and crop management practices, such as how intensively you till and other things like that affect availability. Presence or absence of drainage and type of drainage has an effect on N availability; if you have poor drainage you may experience significant losses of nitrogen. Temperature plays a role as a lot of the mineralization that occurs (as biological processes) is temperature-mediated. Last but not least precipitation plays a role in nitrogen availability. A soil that is too dry will not mineralize nitrogen; a soil that is too wet will not mineralize nitrogen.



These factors also interact in complex ways, making it difficult to precisely predict how much N needs to be added to soil to adequately feed the crop in question. There are some guidelines, however to help make these decisions once we understand the system a little better

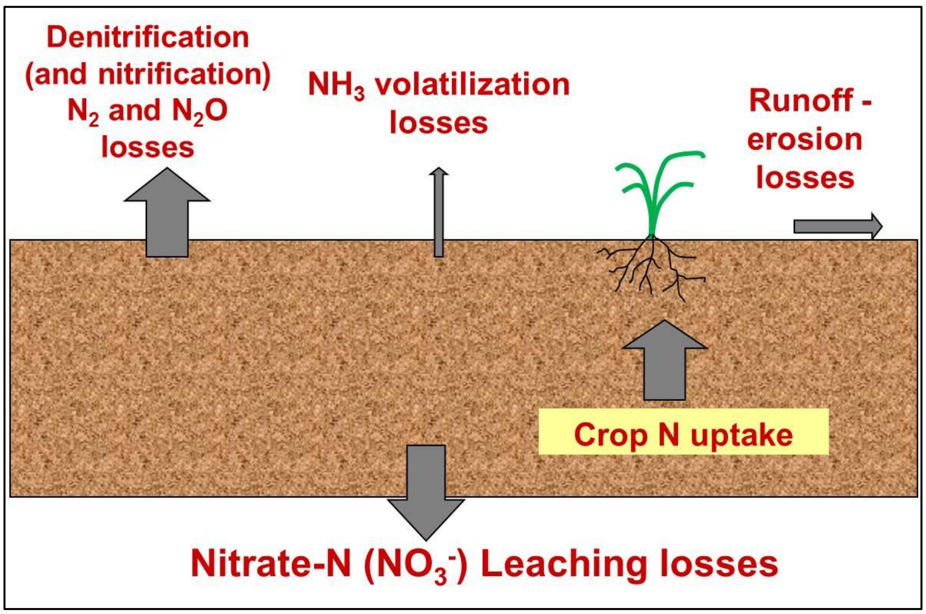
Nitrogen mineralization from soil organic matter

The graph on the right shows nitrogen mineralization as a function of incubation time (*Cassman and Munns, 1980, SSSAJ*). Most of the nitrogen comes from the surface soil, 0 to 18 cm or 0 to 7 inches. . Increasing mineralization occurs up to 10 days. As we go deeper into the soil, less and less nitrogen is mineralized and becomes available. So it's the surface soil that's most important, providing the bulk of the nitrogen. This study was a laboratory study. In the field, N release will be affected by weather conditions, soil organic matter content, and soil type.

Pathways for nitrogen losses

There are five pathways for soil nitrogen losses; the preferred pathway of course is uptake by the crop (*Figure 51*). The other 4 pathways potentially lead to problems. Volatilization is one such pathway. If ammonium fertilizers are applied and left on the soil surface they are subject to volatilization. If they are applied by injection or incorporated immediately after application this potential environmental loss may be minimized/eliminated. The same may be true for manures and composts. If they are left on the soil surface and not incorporated, N may be lost through volatilization. Runoff and erosion, in the case of nitrogen, tend not to be primary loss pathways; the exception to this would be when inorganic or organic materials are left on the soil surface and are subsequently subjected to a heavy rain event. The other major losses are denitrification and nitrate leaching.

Figure 51. *Pathways for nitrogen losses*.



Management, soil health, precipitation and temperature are all critical factors in terms of nitrogen losses. As always, when you get a lot of water you get a lot of leaching. Denitrification is affected both by precipitation and by temperature but it's an indirect loss, and a biologically mediated loss. If you have a very cold soil you may have quite a bit of nitrogen in that soil but you won't get much denitrification loss because the soil is cold and the biological activity is low. When we do see a lot of denitrification losses is a little bit further into the growing season when the soil has become warm and you get a lot of rain; losses may be as high as 30 to 50 pounds per acre from a heavy rainfall event. In a way you'd like to be able to account for that.

Going back to our discussion of pore size and environmental losses; small pores reduce leaching losses; large pores reduce denitrification losses. Ideally you have some of both pore sizes. So the best case scenario for reducing nitrogen losses would be a well aggregated soil of medium texture.

Poor internal drainage

If you have barriers deep in the soil and/or water tables at relatively shallow depths, poor soil internal drainage may result. These promote denitrification losses; poor internal drainage can be remediated through installation of subsurface drain lines. Use of raised beds also reduces susceptibility to imperfect drainage. It's a component often forgotten. Poor drainage creates problems not only with nitrogen losses but also with runoff, erosion and phosphorus losses as the soil remains wet and saturated.

Strategies for reducing nitrogen losses

What are the main strategies then for reducing nitrogen losses? First, do not over apply nitrogen by accounting for all sources of N inputs (soil organic matter, manure, compost, fertilizer, etc.).

Ideally, provide N in multiple applications and account for weather factors (precipitation and temperature). On the scientific front progress has been made in this area. We now have for field corn and sweet corn and ADAPT-N tool that allows for prediction of how much nitrogen is needed using model simulations, accounting for all of the weather effects previously discussed here.

For berry producers, even where a tool like that is not available, you can have basic rules of thumb. If you have a very wet spring you probably lost some of that nitrogen through denitrification and leaching, depending on your soil type, and you may to make up for that by applying a little bit of additional nitrogen in your second application. If you have a relatively dry spring you may want to do the opposite; you didn't have any losses and you want to avoid over applying.

Build and maintain soil health (aggregation, OM, etc.), especially on fine textured soils will help to maintain aeration and with water/nutrient retention. So again soil health management is important from not only a production standpoint but also in terms of managing environmental losses.

And finally, as indicated previously, facilitate good drainage.

Soil health and environmental health potential – a case study

Below are two soil health reports for two very similar soils; one soil had a history of manures inputs, the other had a history of no manure inputs. Even those these two soils are inherently very similar, medium textured soils, you can see the aggregate stability without manure (left) was 53% but became 78% with multiple manure inputs. The manure inputs have actually made the soil more desirable by allowing for better aeration, and subsequently reduced potential for denitrification losses.

The available water capacity went from 0.1 to 6 increasing the ability of the soil to retain both water and nutrients, reducing denitrification losses and leaching losses due to the better nutrient and water retention.

Also notice the organic matter content without manure was 2.6; with the manure additional it is built up to over 6%. That has a lot of benefits. The situation is similar with the active carbon (21 vs. 86) and potentially mineralizable nitrogen; the nitrogen value went from 6 to about 23. The soil on the right can provide more nitrogen than the soil on the left. The soil on the right is of higher quality, more desirable, and presumably is of reduced environmental impact.

Without manure inputs

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	53	83	
	Available Water Capacity (m/m)	0.10	12	water retention
	Surface Hardness (psi)	70	89	
	Subsurface Hardness (psi)	420	9	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	2.6	25	energy storage, C sequestration, water retention
	Active Carbon (ppm) [Permanganate Oxidizable]	460	21	Soil Biological Activity
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	6.2	1	N Supply Capacity
	Root Health Rating (1-9)	3.5	75	
CHEMICAL	*pH	7.9	0	Toxicity, Nutrient Availability (for crop specific guide, see CNAL report)
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	6.0	100	
	*Extractable Potassium (ppm)	50	72	
	*Minor Elements		56	
	OVERALL QUALITY SCORE (OUT OF 100):		45.2	Low

Measured Soil Textural Class:==> silt loam
SAND (%): 40.1 *SILT (%): 51.9* *CLAY (%): 8.0*
Location (GPS): Latitude=> 0 Longitude=> 0
* See Cornell Nutrient Analysis Laboratory report for recommendations

With manure inputs

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	78	99	
	Available Water Capacity (m/m)	0.26	97	
	Surface Hardness (psi)	239	22	rooting, water transmission
	Subsurface Hardness (psi)	350	27	Subsurface Pan/Deep Compaction
BIOLOGICAL	Organic Matter (%)	6.1	98	
	Active Carbon (ppm) [Permanganate Oxidizable]	815	86	
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	22.9	100	
	Root Health Rating (1-9)	5.2	50	
CHEMICAL	*pH	6.7	100	
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	19.5	100	
	*Extractable Potassium (ppm)	228	100	
	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		81.5	High

Measured Soil Textural Class:==> silt loam
SAND (%): 24.3 *SILT (%): 69.2* *CLAY (%): 6.4*
Location (GPS): Latitude=> Longitude=>
* See Cornell Nutrient Analysis Laboratory report for recommendations

Putting it all together

First and foremost, most berry production systems have low environmental impacts from nutrients and sediment. Part of that is inherent with the production practice; the fact you are growing a perennial plant, there's not a lot of tillage going on, there are not a lot of very large amounts of nutrients that get applied.

Site characteristics (soil type, location, etc.) can affect potential losses, for example if you are on a flood plain or have very clayey soils, soils that naturally have higher erosion and runoff potential.

Soil health management has benefits for increased productivity and reduced environmental impacts; a win-win situation.

In addition, we need to be careful what we are putting out there; prudent nutrient management can prevent most of these losses.

Chapter 11 Future Nutrient Management in Berry Crops - *Dr. Bielinski Santos, University of Florida or*

Let's review

Much of the information covered in the previous 10 chapters discuss the topic of nutrient management. For berry production, specifically intensive strawberry production, nutrient management usually requires the grower to understand and properly utilize fertigation techniques. This chapter will explain how berry fertilization and irrigation practices are intertwined and why it is difficult to provide growers with a "one size fits all" recommendation for fertilizing berries.

Fertigation

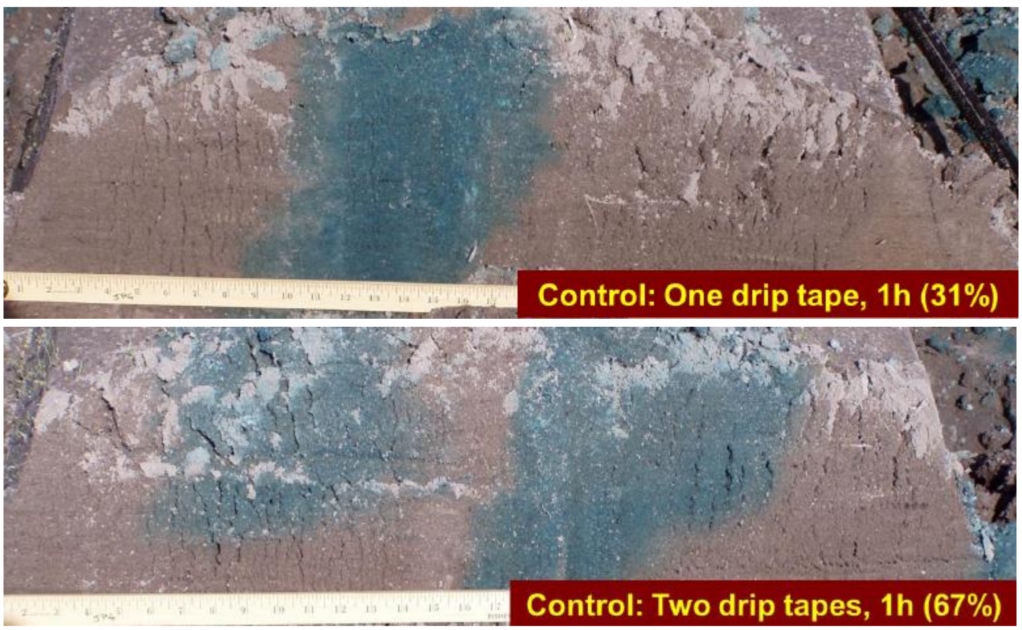
Fertigation is the process by which fertilizers are applied through the irrigation system. This practice relies on two different types of fertilizer: ready to use liquid fertilizer and hydro-soluble salts.

Custom blended liquid fertilizer is the most commonly used product in most large strawberry growing regions. It is very convenient for the grower and can be tailored to the particular need of the plant and the farm situation. The fertilizer does not precipitate out of solution so the accuracy of the dosage is greater. This fertilizer is more costly as the volume and weight of the product makes shipping and delivery more expensive.

Hydro-soluble salts are more affordable but the opportunity for error is greater as the fertilizer needs to be mixed by the farmer. These products do precipitate out of solution so during fertigation it is important that the solution by monitored.

Nutrition and irrigation principles

Nutrients only move as far as the water takes them. No fertigation program is efficient if a poor irrigation program is in place.



Photos at left illustrate water dyed water infiltrating sandy soil in a raised strawberry bed. Using one drip tape (top), only 31% of the bed was moist after 1 hour of irrigation. In the bed that had 2 irrigation tapes (bottom), 67% of the bed was moist after 1 hour of irrigation as illustrated in the lower photo.

There are four fundamental components for success with fertigation:

1) Do not irrigate longer than 1 hour at a time.
2) Use monitoring equipment.
3) Calibrate your soil – i.e. know your field capacity.
4) Keep the water in the rooting zone.

In Florida the typical soil is classified as Spodosol: an ashy gray, acidic soil with a strongly leached surface layer. Because these soils closely resemble beach sand, there is constant danger of nutrient leaching. Keeping the plants sufficiently watered and fertilized while preventing leaching requires a daily or every other day fertigation schedule. Managing this type of soil closely resembles managing a soilless media and although most strawberries grown in the US are grown in soil, increasingly many regions of the country are using protected culture where the berries are grown in a soilless media.

The example of Florida soils illustrates the importance of knowing your own unique soil in order to grow strawberries well. This includes all of the physical and chemical properties of the soil that have been discussed in previous chapters, but also includes considerations of field capacity and the wilting point of berry crops.

Correctly determining field capacity, which is the upper limit of the plant available water in a soil, and permanent wilting point, the lower limit of plant available water, will allow growers to correctly schedule irrigation.

The available water in various soils at field capacity varies tremendously as shown in Table 29.

Table 29. *Total available water of various soils at field capacity.*

Soil Class	Available water storage capacity in acre-inches per foot depth of soil
Gravelly sandy loams	1.0 (27,000 gallons)
Sandy loams	1.35 (36,450 gal)
Gravelly loams	1.75 (47,250 gal)
Loams/silt loams	2.0 (54,000 gal)
Silty clay loams	2.5 (67,500 gal)
Organic (muck) soils	1.0 (27,000 gallons)

Water Monitoring Equipment

Water monitoring equipment varies in price and accuracy. Tensiometers are commonly used because they are easy, inexpensive and decently accurate. They are measuring the water tension in the soil in order to determine available soil moisture. One unit per location is required which can be limiting.

Time Domain Reflectometers (TDR) are more expensive but still easy to use and are very accurate. You will only need one unit for the whole farm. TDR's determine available soil moisture by measuring soil volumetric water. The farm manger could go and check all of the field readings before each irrigation cycle and determine the length of the irrigation event.

Irrigation research depends on even more sophisticated and expensive technology that is not necessary for production agriculture.

Polk county Florida strawberries grown in coconut coir substrate in vertical stackers. The lower levels of stackers may be too shaded, but the upper levels should perform well if fertigation is appropriate.

Soil vs. soilless media

Soilless media is becoming increasingly common in specialty crop production. Most soilless medium is solid substrates, but some soilless systems like hydroponics, and aeroponics rely on liquid or mist media environments to deliver nutrients. Solid soilless media acts as a replacement for natural soil. Many of these media are naturally deficient in most nutrients but still provides root support, nutrient and water retention, gas exchange and a pest free environment. Some of these materials are of a mineral origin including perlite, vermiculite, sand, and rockwool. Others substrates are organic in origin including coconut coir, peat, pine bark, compost and coconut hulls.

Injection equipment

There are two basic types of fertilizer injection equipment; suction fertilizer injectors and constant concentration injectors.

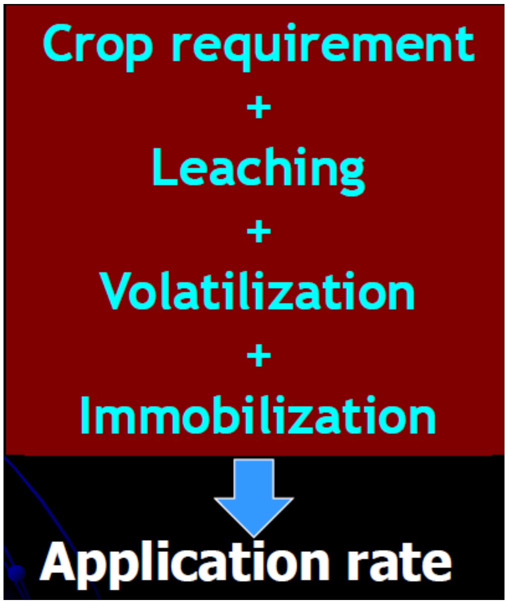
Suction injectors like 'Venturi' ™ systems are easy to use and relatively inexpensive. The drawback with suction systems are that they are consistent only if water pressure is also consistent. If water pressure changes it will change the amount of fertilizer in the line so regular monitoring is required (see drawing at end of chapter).

Constant injection systems, which can be hydraulic or electric, an example is 'Dosatron' ™, supply a constant rate of fertilizer over a broad range of water pressures – if the water pressure drops it will just take a longer amount of time to deliver the required dose, as the rate drops depending on the pressure.

Computerized consoles are the most expensive but they enable the grower to preprogram all of the fertility and the watering ahead of time. These can be worthwhile if you have a trained technician and are fertigating a number of different crops on varying schedules, but more expensive does not always mean better.

A multi tank injection point system provides soluble salt fertilizers separate tanks for all the components of a fertilizer mix. The solids are mixed into solution and stored separately so that they won't precipitate while in the mix. The acids, nitrates, phosphates etc. are stored as a concentrate liquid in their own tank and then are mixed together at the injection point.

Nutrient Rate Determination



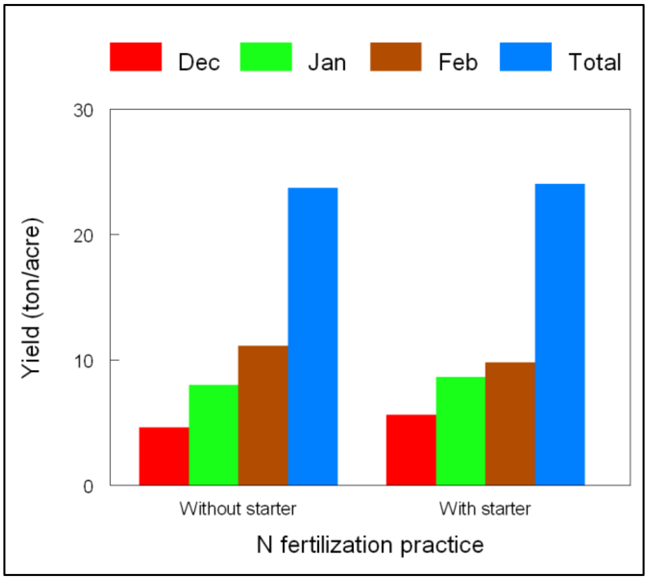
Fertilizer rates are dependent on the source of nutrients, the placement of the nutrient and the timing of application.

Use a soil/medium analysis to determine limiting nutrients. Crop requirement is the first consideration when determining rate, but the grower should also consider the amount of nutrients that may be lost through leaching, volatilization and immobilization so that in the end the crop will still get the necessary macro and micro nutrients.

Blanket recommendations may be used in situations where there is little supporting data in some crops as is the case for some micronutrients like Zn, Fe or Su or if a grower is starting out with a new piece of ground where little information is available.

Crop nutrient requirement varies among cultivars as rates of growth and plant architecture supplies the greatest demand for nutrients.

Preplant and early nitrogen can be applied as a granular fertilizer to the soil or media. Nitrogen and phosphorus can be applied through the drip at the beginning of the crop cycle and then nitrogen and potassium can be added periodically through the drip as needed. Nitrogen and potassium are the most applied nutrients through the season. Nitrogen is almost entirely applied through drip in Florida strawberry production systems.

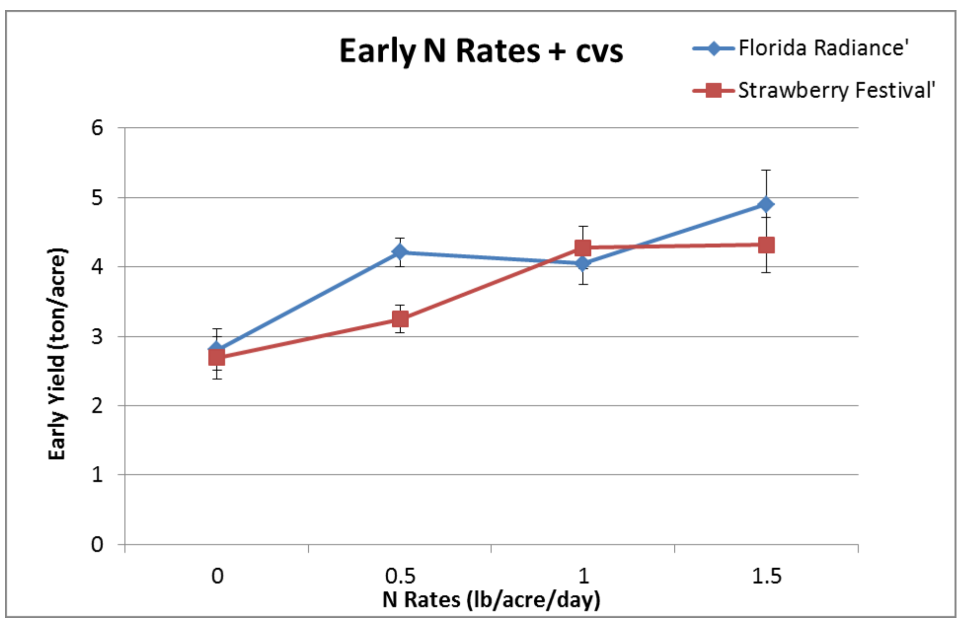


Historically 60% of Florida strawberry acreage had 20-50 lbs/acre of granular ammonium nitrate applied as a starter fertilizer. The remainder of the nitrogen was applied through the drip. Now less than 20% of the acreage follows that protocol. The reason is partially due to environmental concerns and partially because prices have forced growers to make sure the plant is utilizing all of the nutrients applied.

The fact that USDA data reveals that between 2000 and 2011 the cost of all types of nitrogen fertilizers more than doubled and in some cases tripled really helped promote the importance of understanding when N fertilizer was most utilized by the plant.

Studies showed that early N applications did not result in earlier fruit yield, and the optimum rates of N applied varied a great deal depending on the variety. It was also determined that nitrogen sources did not matter, and that plant response at the different rates varied according to cultivar. (See graph below). This work helped save growers $17 per acre and 50 lb of nitrogen per acre.

What about nitrogen and potassium ratios during the season? Studies compared the conventional grower practice of applying fertilizer with a 1.5:1 or 1.75:1 N:K ratio from October transplanting to mid-December followed by a mid-December to March increase of potassium to a 1:1.5 or a 1:2 N:K ratio in order to improve fruit quality. The study did not reveal any differences in 3 different strawberry cultivars in terms of plant diameter, total yields and soluble solids compared to keeping the potassium levels consistent throughout the season. However, there was a difference in cultivar response that indicates N:K ratios should vary during the season. There is a need to derive tailor made fertility programs that depend on the differences in the plant architecture.



Nitrogen sources did NOT seem to make any difference.

Practices should be designed for each specific grower and each specific cultivar type. Once the specific program has been developed, there may be no reason to change the N:K ration during the season.

The only way to determine the specific programs for each of the cultivars will be to understand and use good diagnostic tools.

Diagnostic tools

The best tools for diagnosing problems are your eyes. Visual assessment cannot be beat for catching problems, but often by the time a grower sees a problem it is too late. You want to get to the plant BEFORE the plant looks like the photo at right.

No single tool will provide a one size fits all diagnostics. You will need to several different types of diagnostic tools.

Petiole sap meters are good diagnostic tools for N specifically, but it's difficult to determine the right time to use them. High nutrient levels in the petiole may mean the petiole is simply acting as a nutrient reservoir and nitrogen is not moving through plant vascular system to the leaves.

Colormetric meters like SPAD meters measure the greenness of the leaf and helps to detect deficiencies in nitrogen, magnesium and iron.

When looking at the nutritional composition of the leaves, nothing beats a good leaf analysis – unfortunately time does not stand still while you are getting the information and the leaf analysis is just a snapshot in time. Several days can go by while waiting for the results. The results can be compared to known sufficiency ranges for strawberries. These guidelines are not written in stone, but they allow a grower to fine-tune their fertility program.

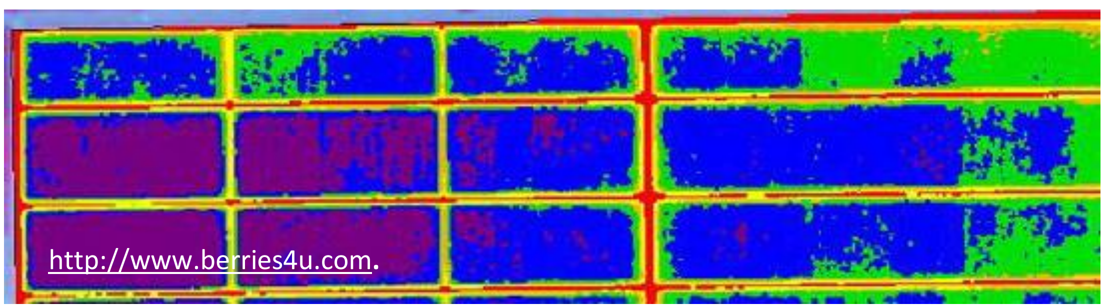
It is very important to make sure that fertigation solutions are correct from the start. Solution pH should never vary from the 6.2- 7.8 range. The soil media will impact the pH. Media may capture and retain more of the nutrients.

Electrical conductivity (EC) should not be too high. In Florida water EC is 0.7 deciseimens per meter – fertilizer solutions should not exceed 2 deciseimens per meter - that requirement will influence the kind of fertilizer needed. A grower might be better off (certainly have more choices) if they lowered the concentration of nutrients and applied fertilizer more frequently.

Table 30. Sufficiency ranges for petiole sap N and K concentrations for Florida strawberries, October planting.		
Month of season	**Petiole sap nutrient concentration (ppm)**	
	NO_3- N	**K**
November, soon after planting	800 - 900	3000 - 3500
December, first harvesting	600 - 800	3000 - 3500
January, main season	600 - 800	2500 - 3000
February, main season	300 - 500	2000 - 2500
March, main season	200 - 500	1800 - 2500
April, late harvest, near end of season	200 - 500	1500 - 2000

Emerging Tools for Improving Production

Aerial infrared photographs are now used as a tool to measure crop leaf reflectance and help diagnose plant stress caused by poor nutrition and pest management. This is primarily in agronomic crops now, but vegetable crop growers are also using the technology.



The photos can point to specific areas where growers might need more nutrients – allowing you to make adjustments as trouble arises. The areas in green in the diagram above indicate areas of poor vigor which are likely to respond to increased fertility. This type of photography combined with a better understanding of crop reflectance measurements are being used increasingly in Europe and will likely be utilized in North America in the near future.

Other innovations include nitrification inhibitors. These help slow down conversion of NH4 to nitrate.

Other coming attractions in research programs include increased evaluations on the effects of other nutrients on growth and quality – specifically the uptake of Phosphorus in the early stages of plant growth – and the management of soilless culture – making sure that each specific soilless medium and their characteristics are understood.

Summary

Berry fertilization and irrigations are both highly intertwined and variable depending on a number of factors, which is why there is no "one size fits all" when it comes to these procedures. In order to have successful fertigation techniques, you must not irrigate longer than an hour at a time, you must use monitoring equipment, calibrate your soil, and keep the water within the rooting zone. Knowing your land and soil type are other valuable tools to practicing efficient fertigation. While there are a number of diagnostic tools to determine problems within your crops, using your eyes and overall judgment can be a valuable tool. Aside from fertigation application techniques, having the proper pH and electric conductivity can result in a better crop yield as well as healthier plants. A combination of all of these ideas will contribute to future nutrients within berry crops.

Figure 52. Venturi injection system

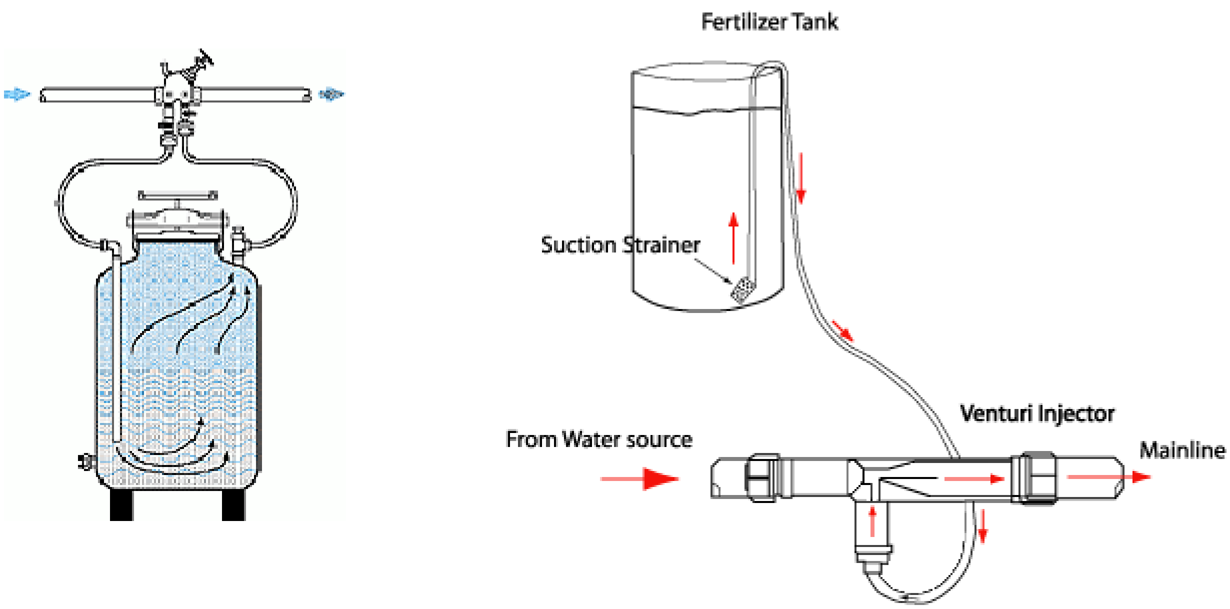
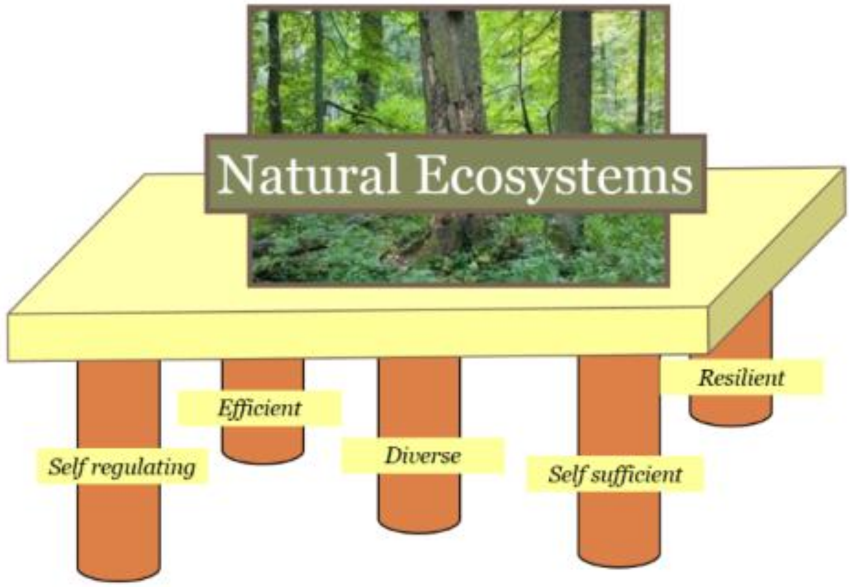


Figure 53. SPAD meter readings may be correlated with N status under certain conditions

Chapter 12 Soil Management Using Ecological Principles and Soil Health Management - *Dr. Harold van Es, Cornell University*

Understanding Agroecology

Agroecology is the application of ecological science to the study, design and management of sustainable agroecosystems. Agroecology enhances agricultural systems by mimicking natural processes which in turn encourages beneficial biological interactions, synergies and efficiencies within the system. An agroecological system recycles nutrients, energy and carbon in favor of external inputs whenever possible. Agroecology provides a framework for approaching agricultural management that is much more knowledge intensive.



Natural ecosystems have evolved over the years into sustainable systems built on the basis of five fundamental characteristics, represented in the graph at _______.

Natural ecosystems are:

- Efficient – in terms of energy, nutrients, water, and carbon. All contribute to the cycle of inputs – there is little to no waste as one organisms waste in this system might be another organisms' resource.
- Diverse – biological diversity leads to check and balances above and below the soil level.
- Self- sufficient – few external inputs are required – primarily sunlight, rain and air. This is very different than traditional agricultural systems.
- Self-regulating – the diversity of the ecological communities promotes a dynamic balance of organisms. It would be uncommon to see a severe pest problem in this type of system.
- Resilient – these systems are able to bounce back after disturbances. For example, natural ecosystems tend to bounce back more quickly than agricultural land if there is damage from extreme weather.

Transforming agricultural systems

Is it possible to create agricultural systems that demonstrate some or all of the characteristics of a natural ecosystem? Agricultural systems often react to limiting factors – many of us have seen the illustration at left. The water barrel with short staves illustrates the limiting factor concept. Rather than repairing the individual stave, which is a reactive management strategy, perhaps we need to buy a new barrel! For example, if nutrients are deficient– rather than just adding fertilizer we should determine WHY the deficiency exists.

Natural ecosystems exhibit more pro-active "management" strategies which allow these systems to be more efficient and resilient. An example of this is the evolution of mycorrhizae in forests – this natural management strategy enhances mutualism and promotes synergy with other organisms.

The "Limiting Factor Concept":

The goal of pro-active, long-term management is to:

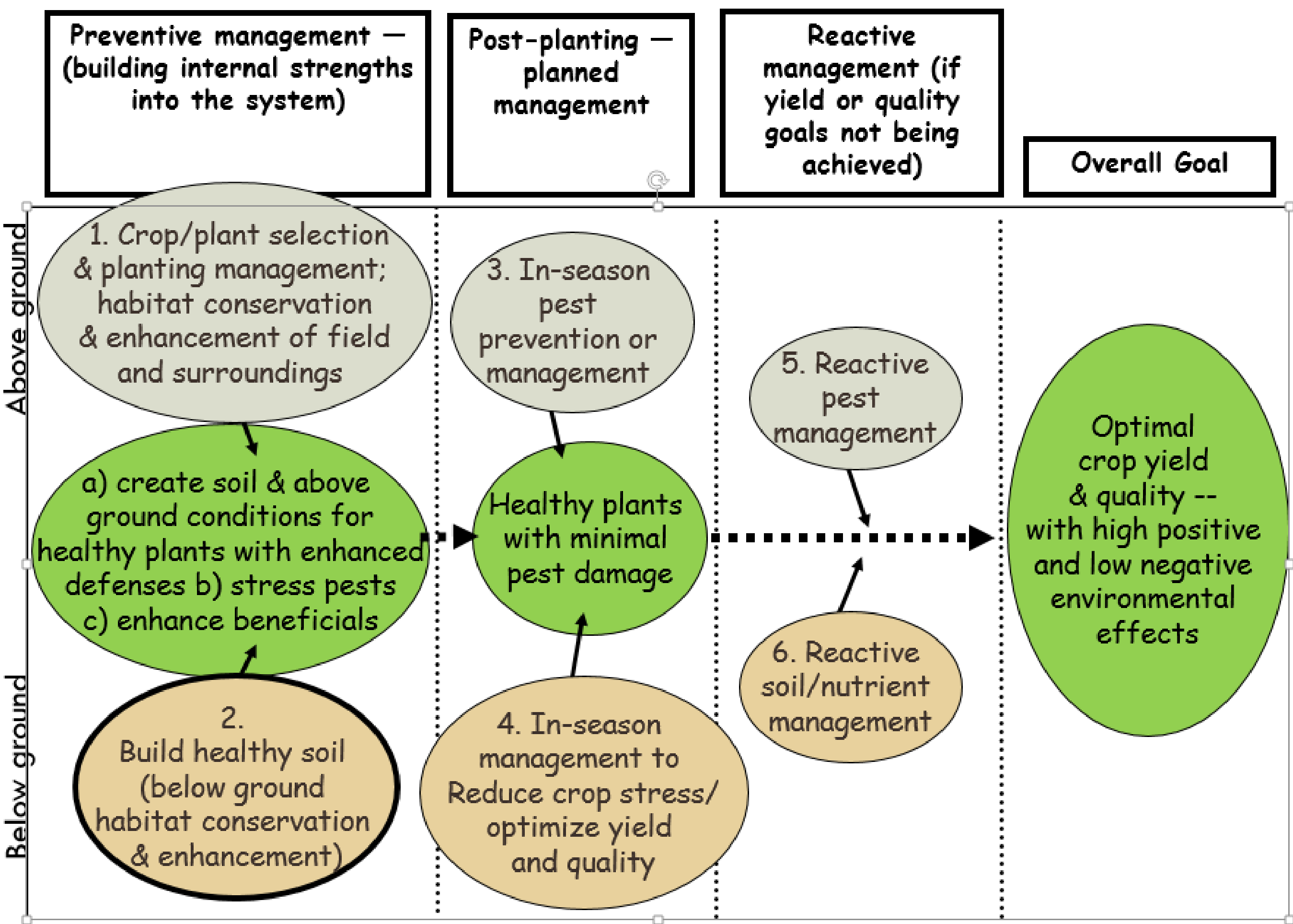
- Enhance mutualism and synergies
- Stress pests
- Enhance beneficials
- Create soil & above ground conditions to promote the growth of healthy crops with enhanced defenses

A whole system approach to soil and crop management at the field level

The chart below illustrates the strategy for long term preventive management. By properly assessing the soil – i.e. evaluating and amending pH, adding OM, reducing compaction - the soil will be healthier.

Above ground preventive management strategies include choosing resistant crop cultivars and then planting them with care. These strategies will enhance the overall success of the plant.

The second level (in-season management) would be a commitment to Integrated Pest Management (IPM) practices and the use of regular tissue testing. The commitment to these types of crop monitoring techniques allows you to grow healthy plants with minimal damage.



The third level of management (reactive management) may be needed if a pest or fertility issue needs more immediate attention. This type of management should be a final strategy to insure crop health and reduce the impact of the problem on the plant.

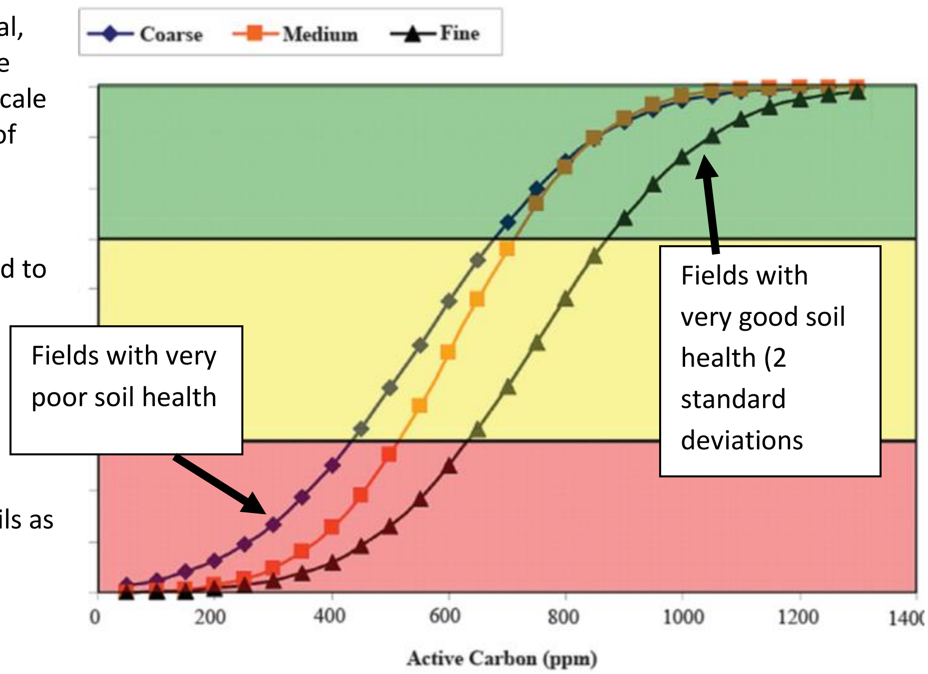
Historically we have focused on reactive management, but research and experience indicate that agriculture needs to move toward a more ecological model of management.

Some examples of ecological management models include:

- Many types of compost have been shown to suppress root disease when used in a potting mix.
- Lower early season Nitrogen levels decrease viability and competitiveness of small seeded weeds.
- Flea beetle pressure and damage to cabbage is more severe on compacted soil.
- Root rot severity of vegetable crops is decreased when crops are grown in cover crop rotation where the cover crops are sufficiently decomposed.
- Many cover crops suppress plant parasitic nematodes.

Pro-active soil management

The Cornell Soil Health Test (CSHT) is a tool that provides farmers the information needed to proactively manage their soil. As has been discussed elsewhere in this manual, the physical, chemical and biological indicators are measured and reported on a rating scale that alerts the farmer to limitations of that unique plot of soil.



The CSHT rating scale has been developed using soil typically devoted to annual agronomic or vegetable crop production systems. The CSHT needs to incorporate the existing information into a rating scale that is appropriate for perennial berry production. This will require more data from berry soils as the rating scale is developed using a frequency distribution of data from many soils.

Perennial system soils often have different values of active carbon and organic matter and can frequently require lower pH. Samples are needed from berry fields that will represent a range of conditions - especially from soils that don't perform well and those that do perform well. Additionally more time needs to be devoted to interpretation of the information.

Summary

Ecological management is a type of proactive management that builds resilience in the cropping system. Reactive management may be necessary to optimize the situation, but BOTH proactive and reactive management techniques are critical. Soil testing remains one of the most important components of ecological soil management but the CSHT needs to be refined for perennial crops to best inform berry growers. Remember, organic matter content is important – but it really isn't everything to a soil.

Additional Resources

1. Hoorman, J., Aziz,I., Reeder, R., Sundermeier, A., and Islam, R. 2011. Soil Terminology and Definitions, OSU Factsheet SAG-11, 8 pp.

GLOSSARY

Term	Definition
active carbon	*the portion of total soil organic carbon (matter) that is relatively easily metabolized or utilized by microorganisms.*
anaerobic	*living without air, as opposed to aerobic.*
anion	*an ion with more electrons than protons, giving it a net negative charge.*
anoxia	*areas of sea water, fresh water or groundwater that are depleted of dissolved oxygen. Anoxic conditions are in a general a more severe condition of hypoxia. The US Geological Survey defines anoxic waters as those with dissolved oxygen concentration of less than .5 milligrams per liter.*
base saturation	*The proportion of acids and bases on the cation exchange complex.*
biochar	*name for charcoal when it is used for particular purposes, especially as a soil amendment. Biochar, a stable solid, rich in carbon, which can endure in soil for thousands of years, increases soil fertility and agricultural productivity, and provides protection against some foliar and soil-borne diseases.*
cation	*is an ion with fewer electrons than protons, giving it a positive charge*
cation exchange capacity (CEC)	*the maximum quantity of total cations, of any class, that a soil is capable of holding, at a given pH value, available for exchange with the soil solution. CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination.*
clay	*a fine-grained soil that combines one or more clay minerals with traces of metal oxides and organic matter.*
compaction	*the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains. Normally, compaction is the result of heavy machinery compressing the soil, but it can also occur due to the passage of (e.g.) animal feet.*
denitrification	*a microbially facilitated process of nitrate reduction (performed by a large group of heterotrophic facultative anaerobic bacteria) that may ultimately produce molecular nitrogen (N2) through a series of intermediate gaseous nitrogen oxide products.*
dynamic soil quality	*those soil qualities that change over relatively short periods of time (months to years) in response to land use or management practice changes. Dynamic properties include organic matter, soil structure, infiltration rate, bulk density, and water and nutrient holding capacity.*
erosion	*the process by which soil and rock are removed from the Earth's surface by exogenic processes such as wind or water flow, and then transported and deposited in other locations*
estuary	*a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea. Estuaries form a transition zone between river environments and maritime environments and are subject to both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment.*
eutrophication	*an ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system.*
evapotranspiration	*the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Evapotranspiration is an important part of the water cycle.*

fragipan	*altered subsurface soil layer > 6 inches (15 cm) depth) that restricts water flow and root penetration*
greenhouse gas	*a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases greatly affect the temperature of the Earth.*
humus	*organic matter that has broken down into a stable substance that resists further decomposition*
hydrologic cycle	*or water cycle, describes the continuous movement of water on, above and below the surface of the Earth.*
hypoxia	*or oxygen depletion is a phenomenon that occurs in aquatic environments as dissolved oxygen becomes reduced in concentration to a point where it becomes detrimental to aquatic organisms living in the system.*
infiltration	*the process by which water on the ground surface enters the soil.*
inherent soil quality	*those soil qualities that change little, if at all, with land use or management practices, for example: soil texture, depth to bedrock, type of clay, cation exchange capacity, and drainage class*
leaching	*the loss of water-soluble plant nutrients from the soil.*
loam	*a soil composed mostly of sand and silt, and a smaller amount of clay (about 40%-40%-20% concentration respectively).*
macropores	*larger soil pores (greater than 60 micrometers) from which water drains readily by gravity. Macropores are important for soil aeration and good drainage.*
micropores	*smaller soil pores (less than 60 micrometers) generally found within soil aggregates. Water does not drain freely in micropores*
mineralization	*the release of plant-available compounds such as ammonium during decomposition*
mycorrhizae	*a fungus that forms a symbiotic relationship with vascular plants enhancing their ability to take up nutrients and water.*
organic matter	*matter composed of organic compounds that has come from the remains of once-living organisms such as plants and animals and their waste products in the environment*
penetrometer	*a device used to measure resistance as it is pushed down into the soil helping to identify compacted layers.*
podzol	*a typical soil of coniferous or boreal forests, often, but not exclusively occurring in wet, cold climates. Most podzols are poor soils for agriculture due to the sandy portion, resulting in a low level of moisture and nutrients. Some are sandy and excessively drained. Others have shallow rooting zones and poor drainage due to subsoil cementation. A low pH further compounds issues, along with phosphate deficiencies and aluminum toxicity. The best agricultural use of Podzols is for grazing although well-drained loamy types can be very productive for crops if lime and fertilizer are used.*
sand	*naturally occurring granular material composed of finely divided rock and mineral particles.*
sediment	*a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particle itself. Sediments are most often transported by water (fluvial processes), wind (Aeolian processes) and glaciers.*
silt	*granular material of a size somewhere between sand and clay whose mineral origin is quartz and feldspar.*
soil	*the unconsolidated mineral or organic material on the immediate surface of the Earth*

	that serves as a natural medium for the growth of land plants
soil aggregates	*primary soil particles (sand, silt, and clay) held together in a single mass or cluster, such as a crumb, block, or prism or clod using organic matter as cementing material.*
soil compaction	*the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains.*
soil crumb	*a unit of aggregated soil that helps provides structure and large pores spaces for free water and air movement.*
soil health	*the capacity of the soil to function*
soil penetrometer	*diagnostic tool to measure the extent and depth of subsurface compaction*
soil profile	*a vertical section of soil from the ground surface to the parent rock showing the different horizons or layers*
soil structure	*is determined by how individual soil granules clump or bind together and aggregate, and therefore, the arrangement of soil pores between them. Soil structure has a major influence on water and air movement, biological activity, root growth and seedling emergence.*
soil texture	*the relative portion of sand, silt, and clay in a given amount of soil.*
soil tilth	*A descriptor of soil combining the properties of particle size, moisture content, degree of aeration, rate of water infiltration, and drainage.*
soil type	*usually refers to the different sizes of mineral particles that comprise a soil; the largest particles, sand, determine aeration and drainage characteristics, while the tiniest, sub-microscopic clay particles are chemically active, binding with water and plant nutrients. The ratio of these sizes determines soil type: clay, loam, clay-loam, silt-loam, etc.*
subsoil	*is the layer of soil under the topsoil on the surface of the ground. Like topsoil it is composed of a variable mixture of small particles such as sand, silt and/or clay, but it lacks the organic matter and humus content of topsoil.*
subsurface compaction	*compaction that occurs below the plow layer due to a surface load; compaction below the normal tillage depth may sometimes remediated by fracturing or cutting.*
suppressive soil	*a soil in which certain diseases fail to develop because of the presence of soil organisms that are antagonistic to those pathogens.*
surface compaction	*compaction that occurs in the surface "plow layer"; this type of compaction may be partly alleviated with normal tillage operations*
surface runoff	*the water flow that occurs when the soil is infiltrated to full capacity and excess water from rain, meltwater, or other sources flows over the land. This is a major component of the water cycle, and the primary agent in water erosion*
top soil	*is the upper, outermost layer of soil, usually the top 2 inches (5.1 cm) to 8 inches (20 cm). It has the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs.*
transpiration	*accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.*
volatilization	*the process where a dissolved compound is vaporized or made volatile; the process of converting a chemical substance from a liquid or solid state to a gaseous or vapor state*

APPENDIX A: How to Determine Your Soil Type using Web Soil Survey (WSS)

Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS) and provides access to the largest natural resource information system in the world. NRCS has soil maps and data available online for more than 95 percent of the nation's counties and anticipates having 100 percent in the near future. The site, located at http://websoilsurvey.nrcs.usda.gov/app/ is updated and maintained online as the single authoritative source of soil survey information.

Requirements for Running Web Soil Survey

Supported Web Browsers

Web Soil Survey has been tested on the following browsers.

Microsoft Windows 7:

- Internet Explorer 9.0
- Firefox 16.0.1
- Google Chrome 22.0.1229.94

Microsoft Windows 7 - USDA CCE:

- Internet Explorer 8
- Google Chrome 22.0.1229.94

Microsoft Windows XP - USDA CCE:

- Internet Explorer 8
- Mozilla Firefox 16.0.1
- Google Chrome 22.0.1229.94

Apple Macintosh OS X:

- Safari 6

Screen Size

The optimal screen size for Web Soil Survey is 1024 × 768 pixels or higher. The software has been tested and works correctly at screen sizes as low as 800 × 600 pixels, but the smaller the screen, the more you will have to scroll.

Display Resolution

The optimal screen resolution for Web Soil Survey is 1024 × 768 or higher. The software has been tested and works correctly at resolutions as low as 800 × 600, but the lower the resolution, the more you will have to scroll.

JavaScript

To run Web Soil Survey, JavaScript is required. If JavaScript is disabled in your browser, the application simply will not work at all. You will see an error message in this case.

Cookies

Web Soil Survey maintains a session between the server and your browser. This requires that *session cookies* be enabled for the Web Soil Survey site. Session cookies are valid only for your current browser session. They are maintained only in browser memory, not written to your system's disk. If session cookies are not enabled, the application will end your session with a message saying session cookies must be enabled.

If you would like Web Soil Survey to remember your preferences after the end of the current session, you must enable *persistent cookies* for the Web Soil Survey site (nrcs.usda.gov). Persistent cookies are written to your system's disk, for use when you return to a web site in the future. Web Soil Survey does not require persistent cookies, except for this feature.

Popup Blocker

By default, Web Soil Survey opens some content in an external browser window, specifically:

- The Web Soil Survey home page
- Links to other sites
- PDFs created by **Printable Version** and "Get Now" in the **Shopping Cart** tab's **Checkout** form.

If you have a popup blocker configured, it will probably not allow this. If you wish to open these types of content in an external browser window, configure your popup blocker to allow popups from this site.
Alternatively, you can configure external content to open in the same browser window. Click the **Preferences** link in the navigation bar at the top of the page. Uncheck "Open Links and PDFs in External Windows" and press **Save Preferences**.

Instructions for using WSS:

1. Browse to the Web Soil Survey home page: http://websoilsurvey.nrcs.usda.gov/app/
2. Click on the green "Start WSS" button
3. Select address from the left navigation bar.
4. On the left side of the browser window, in the **Quick Navigation** panel, click on one of the selection methods. For example, open **Address**, type in the address of the desired location and click **View**.
5. Alternatively, open **State/County**, select your state and county, and click **View**.
6. Before you can view any soil data, you must define your Area of Interest (AOI). You can set your AOI by drawing a rectangle or a polygon on the map, or you can set your AOI to a whole Soil Survey Area. AOIs created using the AOI Rectangle and AOI Polygon tools are limited to a maximum of 100,000 acres, but Soil Survey Area AOIs are not.
7. After the map updates, click the *Zoom In* tool. Then click and drag a rectangle on the map to zoom to an area. Zoom in as close as you need to so you can see streets and landmarks you recognize.
8. After the map updates, click the *AOI Rectangle tool*. Click and drag a rectangle around the area of the map you wish to set as your Area of Interest. To stop in the middle of drawing an AOI and start over, when using the *AOI Rectangle* tool, press the **Esc** key *without releasing the mouse button.* To delete an AOI after drawing it, click the **Clear AOI** button in the **Area of Interest Properties** panel.
9. If the area you are interested in is not rectangular, you can use the *AOI Polygon tool*. Click points on the map to define your AOI. Double-click or CTRL-click the final point to finish. To start over when using the *AOI Polygon* tool, just press the **Esc** key.
10. The application will create the AOI you have specified. To delete an AOI after drawing it, click the **Clear AOI** button in the **Area of Interest Properties** panel.
11. To set your AOI to a whole Soil Survey Area, in Quick Navigation, open the Soil Survey Area form. Choose a state and Soil Survey Area using the dropdowns. Then click Set AOI.
12. Once you have set your AOI, click the Soil Map tab to see the soil map and map unit information.
13. To create a printable document containing the map and information on the Soil Map tab, click the Printable Version button, and then click the View button.

14. To run soil ratings or soil reports, click the Soil Data Explorer tab, then the one of the inner tabs: Suitabilities and Limitations for Use, Soil Properties and Qualities, or Soil Reports.
15. On the left side of the browser window, click the Open All button to expand all the folders, or click an individual folder to list the items within it.
16. Click one of the items to open the form, then set options as desired, and click View Rating or View Soil Report. This will show the data in tabular form and, for the Ratings, in color-coded map form. Click the Legend tab at the left side of the map to see a legend of the Rating values.
17. To create a printable version of the soil data, click Printable Version or Add to Shopping Cart:
18. Printable Version generates a PDF document containing the rating or report that you just ran.
19. Add to Shopping Cart adds the report or map to the shopping cart. You can add multiple ratings and reports to the shopping cart and then create a PDF document containing all the items you added to it. The AOI soil map and the list of map units and their descriptions are added to the shopping cart by default.
20. Once you’re done adding content to the shopping cart, click the Shopping Cart (Free) tab, and then click the Check Out button. This will generate a single PDF containing all the items you added. By default, the Soil Map content is automatically included in your PDF.
21. For best results, limit the number of items you add to the shopping cart to ten or fewer.
22. Throughout Web Soil Survey, context-specific help is available by clicking the Help buttons.

APPENDIX B: Calculating Fertilizer Rates

Conversion factors

To convert from	To	Multiply by
lb/A	lb/100 sq ft	**0.0023**
lb/A	kg/ha	**1.12**
kg/ha	lb/A	**0.893**
lb	oz	**16**
lb/A	lb/sq ft	**0.000023**
Strawberries		
lb/A	lb/100 ft of row	**0.008**
Raspberries and Blackberries		
lb/A	lb/100 ft of row	**0.0184**
lb/A	oz/plant	**0.009**
Blueberries		
lb/A	oz/plant	**0.015**
Currants and Gooseberries		
lb/A	oz/plant	**0.012**
lb/A	lb/100 ft of row	**0.0184**

Nitrogen sources and actual N calculations

To calculate the actual amount of fertilizer to apply, divide the desired amount of actual N (table below) by the percent N in the fertilizer and then multiply the result by 100. Apply the total amount of fertilizer in a 3-foot band in the row (1 foot band over the row for strawberries).

Nitrogen sources and calculation of actual N	
Fertilizer	**% actual N in fertilizer**
Ammonium nitrate	34.0
Ammonium sulfate	20.5
Calcium nitrate	15.0
Diammonium phosphate	17.0
Potassium nitrate	13.0
Urea	46.0

Example 1: How many pounds per acre of calcium nitrate should be applied on strawberries to give you an actual application rate of actual N 30 lbs/A?

Calculation:

$$\frac{\text{30 lbs/A actual N}}{\text{15 percent N in calcium nitrate}} \times 100 = \text{200 lbs/A calcium nitrate}$$

Example 2: The grower only has 500 feet of row – not an entire acre. How much calcium nitrate should be applied to provide a 200 lb/A rate of calcium nitrate?

0.008 lb/100 ft row X 200 lb/A = 1.6 lbs/100 ft of strawberry row

5 X 1.6 = 8 lbs. of calcium nitrate for the entire 500 feet

Example 3: How many pounds per acre of ammonium sulfate should be applied to a blueberry field to give an actual application rate of N 60 lb/A?

Calculation:

$$\frac{\text{60 lbs/A actual N}}{\text{20.5 percent N in ammonium sulfate}} \times 100 = \text{293 lbs/A ammonium sulfate}$$

Example 4: The grower will only be planting a 400 square foot area, not an entire acre. How much total sulfur will be required if the site has loamy soil and the current pH is 5.5?

Table 1 recommends 1000 lbs/A sulfur

1000 lbs/A X 0.0023 (see Appendix A) = 2.3 lb/100 sq. ft

2.3 X 4 = 9.2 lbs/400 sq. ft.

Additional Resources

1. Hitchcock, R. and Kissel, D.E. *University of Georgia Fertilizer NPK Soil Fertilizer Calculator* http://aesl.ces.uga.edu/soil/fertcalc/

APPENDIX C: Typical composition of some chemical sources of fertilizer nitrogen and potassium

	Percent by Weight of Fertilizer				
Fertilizer	**N**	**P_2O_5**	**K_2O**	**MgO**	**S**
Ammonium sulfate	20.5	--	--	--	24.0
Anhydrous ammonia	82.0	--	--	--	--
Ammonium chloride	25.0-26.0	--	--	--	--
Ammonium nitrate	33.0-34.0	--	--	--	--
Ammonium nitrate-sulfur	30.0	--	--	--	5.0-6.0
Ammoniated ordinary super phosphate	4.0	16.0	--	0.5	10.0
Monoammonium phosphate	11.0	48.0-55.0	--	0.5	1.0-3.0
Diammonium phosphate	18.0-21.0	46.0-54.0	--	--	--
Ammonium phosphate-sulfate	13.0-16.0	20.0-39.0	--	--	3.0-14.0
Superphosphate (TSP)		46			
Calcium nitrate	15.0	--	--	--	--
Potassium nitrate	13.0	--	44	0.5	0.2
Sodium nitrate	16.0	--	--	--	--
Urea	45.0-46.0	--	--	--	--
Potassium chloride	--	--	60-62	--	--
Potassium sulfate	--	--	50-52	--	17
Potassium magnesium sulfate (Sul-Po-Mag)	--	--	22	11	22
Potassium nitrate	13	--	44	--	--
Potassium and sodium nitrate	15	--	14	--	--
Manure salts	--	--	22-27	--	--
Potassium hydroxide	--	--	83	--	--
Potassium carbonate	--	--	<68	--	--
Magnesium sulfate (Epsom salts)				10	

(Source: Bushway, L., Pritts, M., and Handley, D. 2008. Raspberry and Blackberry Production Guide.)

APPENDIX D: Micronutrient Sources

Nutrient	Product	Application Method*	Rate
Boron	Solubor (20% B)	Foliar	1.5 lb/A
		Ground	5.0 lb/A
	Borax	Ground	10.0 lb/A
Copper	Copper chelate	Foliar	Label rates
Iron	Iron Chelate	Foliar	Label rates
Manganese	Manganese chelate	Foliar	Label rates
	Manganese sulfate (32% Mn)	Foliar	2 lb/A
Zinc	Zinc chelate	Foliar	Label rates

*(Source: Pritts, M. and Hancock, J. 1992. Highbush Blueberry Production Guide) *Apply foliar sprays when leaves are present; use 100-200 gal/A. Apply ground sprays at any time; use 20-50 gal/A. (Source: NRAES-55 Highbush Blueberry Production Guide)*

APPENDIX E: Nutrient Content of Organic Materials Used for Macronutrient Supplementation

	Percent by Weight of Material[1]			
Fertilizer	**N**	**P_2O_5**	**K_2O**	**Release rate**
Animal tankage (dry)	7	10	0.5	Medium
Bone meal (raw)	2-6	15-27	0	Slow
Bone meal (steamed)	0.7-4.0	18-34	0	Slow-Medium
Castor pomace	5	1.8	1	Slow
Coca shell meal	2.5	1.0	1	Slow
Compost (not fortified)	1.5-3.5	0.5-1.0	1.0-2.0	Slow
Cottonseed meal (dry)	6	2.5	1.7	Slow-Medium
Dried Blood (dry)	12	1.5	0.57	Medium-Rapid
Fertrell-Blue label	1-5	1	1-2	Slow
Fertrell-Gold label	2	1	2	Slow
Fertrell-Super	3	2	3	Slow
Fertrell-Super N	4	2	4	Slow
Fertrell-Super K	3	4	7	Slow
Fish meal (dry)	10	4	0	Slow
Fish meal (scrap)	3.5-12	1-12	0.80-1.6	Slow
Garbage tankage (dry)	2.7	3	1	Very slow
Guano (bat)	5.7	8.6	2	Medium
Guano (Peru)	12.5	11.2	2.4	Medium
Kelp[2]	0.9	0.5	4-13	Slow
Manure[3] (fresh)				
Cattle	0.25	0.15	0.25	Medium
Horse	0.3	0.15	0.5	Medium
Sheep	0.6	0.33	0.75	Medium
Swine	0.3	0.3	0.3	Medium
Poultry 75% water	1.5	1.0	0.5	Medium-Rapid
Poultry 50% water	2	2	1.0	Medium-Rapid
Poultry 30% water	3	2.5	1.5	Medium-Rapid
Poultry 15% water	6	4	3	Medium-Rapid
Marl	0	2	4.5	Very slow
Milorganite (dry)	5	2-5	2	Medium
Mushroom compost	0.4-0.7	0.6	0.5-1.5	Slow
Peat and Muck	1.5-3.0	0.25-0.50	1.0	Very slow
Sawdust	4	0.2	0.4	Very slow

Sewage sludge (activated, dry)	2-6	307	0-1	Medium
Sewage sludge (digested)	1-3	0.5-4	0-0.5	Slow
Tanbark[4]	0	1.5	2	Very slow
Tobacco stems (dry)	2	0.7	6.0	Slow
Urea[5]	42-46	0	0	Rapid
Wood ashes[6]	0	1-2	3-7	Rapid

(Original source: Pennsylvania State University "Organic Gardening Culture and Soil Management"; updated for this publication 4/14)

[1] The percent of plant nutrients is highly variable, and with some materials, mean percentages are listed.
[2] Contains common salt, sodium carbonates, sodium and potassium sulfates.
[3] Plant Nutrients available during year of application.
[4] Contains Calcium.
[5] Urea is an organic compound, but some organic growers/certifiers consider it unacceptable because it is synthetically produced.
[6] Potash content depends on the tree species burned. Wood ashes are alkaline, containing approximately 32% CaO and may have an effect on pH.

APPENDIX F: Cover Crops for Blueberry Plantings (*Dr. Marvin Pritts, Cornell University*)

The blueberry grower can use cover crops in several ways that will improve the health and productivity of a blueberry planting. Cover crops can be used before the blueberries are planted, plants can be set into a killed cover crop, and cover crops can be seeded between the rows of established plantings. In all three cases, cover crops help to improve soil structure and organic matter content, and suppress weeds and possibly nematodes.

Preplant Cover Crops

Seeding a cover crop on a proposed planting site a year or two before planting is an excellent way to improve soil structure, especially on sandy soils where organic matter content may be low. Cover crops will prevent erosion on sloped sites prior to planting blueberries. Most cover crops grow under a wide range of soil conditions, and except for small additions of N, P and K (typically 40 lbs/A of each), other amendments are not likely to be required. Although the optimal pH for most cover crops is 6 - 7, most grasses will grow satisfactorily at a soil pH of 4.5 or higher.

Minimum seeding rates are used when the objective is to supply an acceptable stand for harvesting the grain or straw. But when a vigorous, dense stand is desired for weed suppression and organic matter, higher seeding rates are used. Small grains or seed from clover or buckwheat cover crops can be harvested and sold to recoup establishment costs.

Preplant cover crops are usually plowed under in the late fall or early spring prior to planting. Those with low nitrogen contents (grains and grasses) should be plowed under in fall to allow adequate time for decomposition. Legumes contain more nitrogen and decompose quickly, so can be turned down within a month of planting. However, the pH of a blueberry site is likely to be too low for good growth of a legume (e.g. alfalfa, clovers and vetches).

Preplant covers as killed sods

Some growers are experimenting with planting berry crops into a mowed or killed sod of grain rye, rather than planting into bare soil. This method reduces the requirement for herbicides in the first year - at a time when many plants are sensitive to even low rates.

A sod residue suppresses weeds for several weeks while the blueberry row becomes established, and minimal soil disturbance results in reduced weed seed germination. To use this system, seed grain rye in autumn, and mow it in spring when the rye plants start to flower (or spray it with an herbicide). Wait a couple of days then plant into the rye residue. Apply mulch down the rows of plants. With this system, creating bare soil suitable for weed growth is minimized. Weeds are controlled for 6 to 8 weeks after planting without any herbicide, and for even longer when followed by a preemergent herbicide and a mulch.

Alleyways

Many blueberry growers find it advantageous to establish a permanent sod cover in the alleyways of blueberry plantings. A sod alley allows pickers to enter the field shortly after a rain and prevents injury to the root system of the blueberry plant that occurs when row middles are cultivated. Alleyways must be mowed, and occasionally fertilized, but otherwise require little maintenance.

Perennial grasses (i.e. ryegrass and fescues) are the best choices for row middles. They establish well, do not grow tall, and do not spread laterally at a fast rate. However, they are sufficiently competitive with other plants to reduce weed numbers in the planting. Seed permanent cover crops in September, if possible, when temperatures are cooler and rainfall is more dependable. If grasses are seeded in late spring, overhead irrigation may be required to promote germination. Some growers seed the entire area with grass the autumn prior to planting blueberries and then spray out strips with glyphosate prior to planting. Others plant the blueberries first then seed the grass in September of the first growing season.

Selecting a cover crop

The selection of a cover crop should depend upon several conditions: 1) time of year when a cover crop is desired, 2) the crop to follow, 3) pH and soil fertility, 4) available tillage equipment, and 5) the length of time the crop will be allowed to grow. The following are descriptions of a few cover crops suitable for use in low pH soils. The relative characteristics of cover crops for low pH soils are discussed.

Preplant only

Buckwheat. This crop is a useful preplant cover on a site with a low soil pH. While the top portion of the plant grows quickly, there is little organic matter contribution from the roots. Reseeding will occur readily if plants are allowed to go to seed, so incorporate shortly after flowering. Earlier seedings in late May or early June are superior to summer seedings in late July.

Annual Field Brome. This is a fast establishing winter annual grass that has a much more extensive and fibrous root system than most other green manure crops. Seedings made during July and August tend to be much more successful than seedings made in late the spring. The following year's spring growth is rapid and after the seed ripens in July, the crop will die. If the soil is disked when the seeds start to fall, then the crop can be reestablished easily with no further seeding. Plan to thoroughly disk or plow down this heavy root system early in the spring. This seed is not readily available so plans for obtaining it should be made well in advance of the normal seeding date. Annual field brome is usually seeded at a rate of 20 pounds per acre.

Japanese Millet. This is a fast growing summer annual which will compete well with weeds and will establish faster on cooler soils than sudangrass. Planted from late May to mid-July, this plant will achieve a height of four feet in seven or eight weeks. Unlike small seeded legumes and grasses, the seed of millet should be covered from 3/10 to 1 inch deep in a firm seedbed. The planting may be cut back and allowed to regrow at any time after twenty inches of growth is obtained. Millet should not be allowed to mature and drop seed. The seed of millet is relatively inexpensive; at a seeding rate of 20 pounds per acre the cost of seed is approximately $7.00.

Spring Oats. When used as a very early spring green manure crop, oats should be planted in early to mid-April. Because of oats fast spring growth, plan to incorporate them into soil in early to mid-June. Oats will grow on soils of relatively low soil pH (5.5) and with moderately good fertility; however, this crop requires good soil drainage. A mid-August seeding will provide good growth and ground cover for protection against soil erosion during the fall and winter months. Oats will be gradually killed back by successive frosts and will not grow again in the spring. The dead plant residue is easily incorporated with very light tillage equipment. Three bushels of oats are usually planted (approximately 100 pounds) at a seed cost of $17.00 per acre.

Annual Ryegrass. Seedings establish very rapidly in spring or late summer. Ideal dates for spring seedings range from early April to early June and late summer seedings are more successful when made from early August to early September. The heavy root growth and the rapid seeding development make annual ryegrass a very desirable green manure cover crop in areas where good soil-water relations can be maintained. The ryegrass will die out early in the second year leaving a heavy root system and a moderate top growth residue to incorporate into the soil. A seeding rate of 30 pounds per acre is suggested, at an approximate cost of $15.00.

Sudangrass. This is a summer annual that requires heat for good growth. Seedings made in late May or early June will guarantee a more vigorous growth than seedings made in late June or early July. Hybrid sudangrasses may have larger seeds and should be planted at heavy rates. Like millet and sorghum-sudan hybrids which have large seeds, sudangrass should be seeded to a depth of one half to one inch into a firm seedbed. Similarly, this summer annual will recover following removal of the top. Due to the tall habit, the crop should be cut back when growth exceeds 20-25 inches or plowed down if a second growth is not desired.

Sorghum-sudangrass hybrids. This summer annual requires more heat for growth than sudangrass. It is more expensive to establish and fails to adapt to most soils as readily as Japanese millet. This crop will grow to a greater size than sudangrass under ideal conditions of heat, moisture, and fertility, but the 4-6 foot growth is very difficult to incorporate with small or moderate sized tillage equipment. Like sudangrass, this crop will make a second growth if climatic conditions will permit. Growth will cease by mid-September in years when night temperatures drop to near freezing. The seeding rate will vary from 35-50 pounds depending upon the size of the seed; therefore, the cost of seed can range from $20.00-30.00 per acre.

Marigolds. Marigold is a relatively new cover crop that has generated much interest among berry growers for its ability to suppress weed and nematodes. Marigolds are commonly used as a preplant cover crop in Northern Europe. As a warm season crop, marigolds germinate only when soil temperatures exceed 65F. Seed at the rate of 5 lb/A and shallowly incorporate the seed. Overhead irrigate to promote germination. Plants do not have to flower to provide benefits.

Use open-pollinated seed rather than the expensive hybrid seed. Open-pollinated seed sells for about $30/lb. Little is known about suitability of various varieties of marigold as a preplant cover crop.

Winter Rye. This cereal grain establishes fast from late summer and early fall seedings, even on low pH soils. Fall seedings made after October 1 are likely to provide only winter cover and are slower to produce heavy spring growth. Excessive early spring top growth can create tillage problems if the crop is not incorporated by early to mid-May. This date will vary with the location and season. The seed is readily available at a cost of $20.00 for the 100 pound seeding rate. Seed is often sold in bushel quantities of 56 pounds.

Permanent row middles

Fescues**.** Several types of fescues are available for permanent row middles such as creeping red, Chewings, hard and tall. Each are seeded at a rate of 70 - 80 lbs/A in April-May or August-September, and costs about $3.00/lb. Tall fescue is most tolerant of the four to low pH soils. Often these are sold as mixtures with other species because most fescues are slow to establish. These companion mixes consist of species that germinate and establish quickly, but are less competitive so will later be replaced by them. Creeping, Chewings and hard fescues require little mowing.

Perennial Ryegrass. Seedings of perennial ryegrass become established faster than seedings of other common perennial grasses such as the fescues, timothy, bromegrass and orchardgrass. Perennial ryegrass can be used as a preplant cover crop because the fibrous root system and vigorous top growth provide substantial material for incorporating into the soil in early spring. Also, perennial ryegrass can be used as a permanent grass for between the rows, and some varieties require little mowing. The dry matter root growth is approximately equal to the top growth. With many crops, the top growth represents sixty to seventy percent of the material turned under at plowing. A 25 pound seeding rate results in a seed cost of approximately $30.00 per acre.

Table 31. *Relevant characteristics of various cover crops for low pH soils*.

Cover crop[1]	Water use	Establishment	Vigor	Durability
Hard fescue	Mod[2]	F	Lo	Ex
Tall fescue	MHi	G	Hi	Ex
Creeping red fescue	Mod	VG	Lo	VG
Chewings fescue	Mod	G	Lo	VG
Perennial ryegrass	Mod	G	Mod	G
Annual ryegrass	Mod	G	Mod	P
Rye (*Secale cereale*)	Hi	VG	Hi	P
Buckwheat	Hi	VG	Hi	P
Sudan grass & hybrids	Hi	VG	Vhi	P
Oats	Hi	VG	Hi	P
Marigold	Hi	F	Mod	P

[1]Mixtures of sod grass types may perform better than single species.

[2]Key to ratings: P=poor, F=fair, G=good, VG=very good, Mod=moderate, MHi=mod high, Ex=excellent, Hi=high, Lo=low.