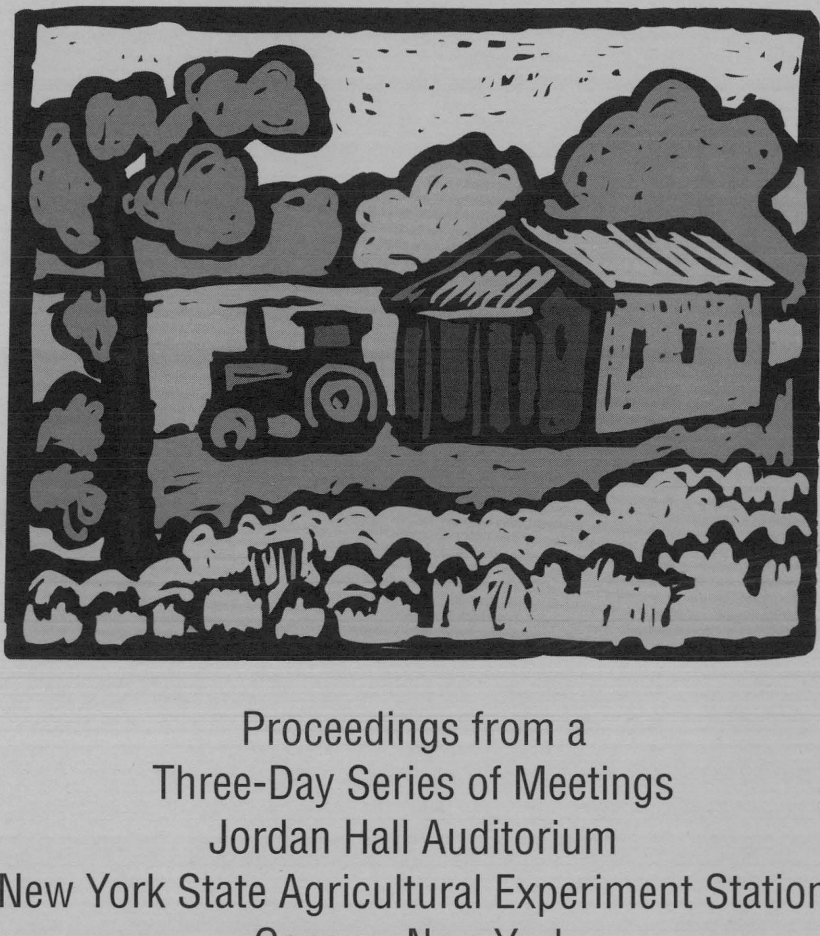
Natural Resource, Agriculture, and Engineering Service NRAES—165

Organic Vegetable Production



Proceedings from a
Three-Day Series of Meetings
Jordan Hall Auditorium
New York State Agricultural Experiment Station
Geneva, New York
January 14–16, 2003

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About the Workshop and Proceedings

The workshop was coordinated by Abby Seaman, Area Extension Educator, New York State Integrated Pest Management Program, Cornell Cooperative Extension. The proceedings was edited by Abby Seaman.

These meetings were intended for commercial vegetable growers who are currently growing organically or want to learn more about organic practices, as well as beginners contemplating organic vegetable production. University and farmer speakers covered the basics of soil and nutrient management, weed management, and insect and disease management.

Thanks to Speakers

The workshop coordinator and NRAES would like to thank the speakers for their diligence in submitting their papers for these proceedings.

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Proceedings Production

Jeffrey S. Popow, NRAES managing editor, designed the proceedings and managed the proceedings project.

About NRAES

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Cooperative Extension

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Natural Resource, Agriculture, and Engineering Service (NRAES)
Cooperative Extension
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About the Speakers

Paul Arnold and Sandy Arnold have been farming at Pleasant Valley Farm for 12 years and raise about 8 acres of organic fruits and vegetables on their 60 acres in Washington County, New York, with two children. Their living is made by selling all of their produce at 4 area farmers' markets.

Brian Caldwell is the education director for NOFA-NY. He is also an experienced grower of organic vegetables and fruit at Hemlock Grove Farm in West Danby, New York.

Jean-Paul Courtens, the founding farmer of Roxbury Farm, was born and raised in the Netherlands, where he studied biodynamic agriculture. Roxbury Farm grows vegetables, herbs, melons, and strawberries using biodynamic practices on 148 acres in Kinderhook, New York for a CSA of 650 families in four communities.

Helene Dillard has conducted basic and applied research on the biology, ecology, and management of fungal and bacterial pathogens of vegetables at the New York State Agricultural Experiment Station in Geneva, New York since 1984. She has been the director of Cornell Cooperative Extension, a primary outreach unit of Cornell University, since 2002.

Vern Grubinger is the director of the Center for Sustainable Agriculture at the University of Vermont. He has extensive experience in many aspects of organic and sustainable vegetable and small fruit production. He is the author of the book *Sustainable Vegetable Production from Startup to Market.*

Cliff Hatch has over 20 years of experience in organic production. He grows a variety of vegetables, strawberries, and grains at Upingill Farm in Gill, Massachusetts.

Ruth Hazzard is team leader for the Vegetable Program and also coordinates the Integrated Crop and Pest Management Project for vegetables. Her research has focused on insect and disease management in brassicas, sweet corn, tomato, and peppers. Currently she is involved with studies on biointensive insect management in brassicas, cucurbits, and sweet corn.

Mike Hoffmann is the director of the New York State IPM Program and a professor in the Department of Entomology in Ithaca. His research and extension program focuses on alternative insect management strategies.

John Howell recently retired as Extension Vegetable Specialist at the University of Massachusetts. His areas of special interest include vegetable production systems, nutrient and soil management, greenhouse tomato production, trickle irrigation and fertigation, and water garden construction and maintenance.

David Marchant and Jane Sorensen operate River Berry Farm alongside the LaMoille River in the Champlain Basin of Vermont. They grow approximately 40 acres of certified organic vegetables, 4 acres of IPM managed strawberries, and 15 acres of grain. The vegetables are marketed out of state through the Deep Root Organic Cooperative, and locally through stores and farmers markets.

Chuck Mohler is a senior research associate in the department of Crop and Soil Sciences. Most of his work has focused on the effects of tillage, cultivation, and crop residue on the population dynamics of annual weeds. He is a coauthor of the book *Ecological Management of Agricultural Weeds.*

Steve Mong, his wife Kirsten, and brother Ray have operated Applefield Farm for 20 years. It is a 25-acre farm with 20,000 square feet in greenhouses, which are used for bedding plant, hanging basket, annual, and perennial production. Steve has been an active cooperator in University of Massachusetts pest management trials.

Anne and Eric Nordell grow vegetables, herbs, and strawberries on 6.5 acres in Trout Run, Pennsylvania. They have developed an elegant whole farm approach to nutrient and weed management. Their produce is marketed through grocery stores, restaurants, and farmers' markets.

Curt Petzoldt is the Assistant Director and Vegetable Coordinator at the New York State IPM Program. For the past ten years he has conducted multidisciplinary trials comparing the environmental and economic attributes of conventional, IPM, and organic production systems at the research farm and on growers' farms.

Anu Rangarajan is an associate professor in the Department of Horticulture at Cornell and statewide specialist for Fresh Market Vegetable Production. Her research program focuses on specialty crop variety trials, and developing production systems that minimize chemical fertilizer and pesticide inputs and maximize crop nutritive value.

Janice Thies is an associate professor of soil biology who joined the Cornell faculty in 2000. Janice's research program focuses on three main areas: soil microbial population genetics, the influence of management practices on soil microbial community structure, and the development of biofertilisers and biopesticides for use in low-input agriculture.

Harold van Es joined the Cornell faculty in 1988. His research, extension, and teaching programs address the management of soil and water resources for sustainable agricultural production and environmental protection. He is a coauthor of the book *Building Soils for Better Crops.*

Soil and Nutrient Management

Soil Life

Janice Thies
Associate Professor
Department of Crop and Soil Sciences
Cornell University

The diverse and numerous creatures living in the soil provide a variety of benefits to crops and but also have potential detriments. The benefits include the decomposition of organic matter, nutrient cycling and release, nitrogen fixation and mycorrhizal relationships, disease suppression, and soil structure improvement. Potential detriments include immobilization of nutrients and the ability to cause plant and animal disease.

Soil food web

The complex network interactions that occur between organisms in the soil is sometimes described as the soil food web. Plants are the foundation of the soil food web, capturing energy from the sun through photosynthesis and providing the organic matter that other organisms work on. Decomposers such as bacteria and fungi work on the material produced by the plants releasing nutrients in a form that is usable by plants. Small arthropods, nematodes, protozoa, and earthworms shred and consume the organic matter produced by the plants, making it more available to the bacteria and fungi, and also consume the bacteria and fungi themselves, releasing plant-available nutrients. Larger arthropods and small mammals then consume the smaller creatures releasing more nutrients.

Soil arthropods

There are four major groups of soil arthropods. Predators such as ants, ground beetles, and spiders help control crop pests. Another group including dung beetles, mites, and sow bugs shred organic matter. Fungal feeders such as springtails and turtle mites release nutrients tied up in fungal biomass. And herbivores such as mole crickets and symphylans can cause crop damage by feeding on roots. Functional roles of arthropods include shredding of organic matter which stimulates microbial activity, mixing microbes with organic matter, mineralizing plant nutrients, increasing aggregation of soil, burrowing, which increases soil channels, preying on other arthropods, and feeding on plants.

Earthworms

Earthworms are another important group soil organisms, considered by some to be soil ecosystem engineers. They move tremendous amounts of soil through their guts as they burrow. In the process, they stimulate microbial activity, mix and aggregate soil, increase soil infiltration rate and water holding capacity, create channels for plant roots, and bury and shred plant residues.

Nematodes

Soil nematodes are very small (300-500 µm), ubiquitous and abundant in soils. They depend on water films on soil particles to swim and survive. They have a range of feeding strategies including plant parasites, bacterial and fungal feeders, predators, or omnivores. The different types of nematodes can be distinguished by their mouthparts. Plant parasitic nematodes have a characteristic stylet with a basal bulb, to penetrate roots. Bacterial feeders have a wide mouth opening to gather in bacteria. To evaluate the health of a soil, some researchers examine the ratio of different types of nematodes. Their functional roles in soils are to feed on bacteria, fungi, and protozoa and in turn release plant available-nutrients, feed on other soil organic matter, affecting soil structure and carbon utilization, or parasitize plants and animals.

Protozoa

Three types of protozoa can be found in soil: ciliated, flagellated or amoeboid. They are animal cells (which have no cell walls, just the cell membrane), and are therefore susceptible to and good indicators of the presence of environmental toxins. In animals, certain types of protozoa can cause disease. In soils, their principal functional role is as primary consumers of bacteria. In this way, they regulate bacterial populations, increase the turnover of soil microbial biomass and organic matter, maintain plant available nitrogen, and decrease establishment of plant pathogens. They are also food for nematodes and fungi.

Fungi

Fungi have diverse roles in soil. They produce digestive enzymes and function as primary decomposers. They can be saprophytes, predators of nematodes, parasites of other fungi or plant pathogens. The production of hyphae by saprophytic fungi can be extensive, and forming a dense web in soil, and helping to improve soil aggregation. Fungi are the organisms with greatest biomass in soil. Symbiotic fungi such as mycorrhizae form associations with plant roots that enhance the survival of both plant and fungi. Some mycorrhizae, such as many ectomycorrhizae, are good saprophytes, and function independent of plants. The ectomycorrhizae associate primarily with trees. These associations consist of a sheath surrounding the root and limited intercellular penetration between cells in the root cortex. The endomycorrhizae associate primarily with crop plants. In this symbiosis, the fungi penetrate the root cortex to form an intimate relationship with host cortical cells. In both symbioses the integrity of the plant cell membrane remains intact and is the site of nutrient exchange with the fungus. In general, mycorrhizae improve the nutrient status of the plants (especially for phosphorus), and may protect plants from exposure to salt, desiccation, toxins or pathogens. The plant provides energy to the mycorrhizae in the form of carbon compounds. The external fungal hyphae explore more soil volume than the root itself, especially for phosphorus. This element is quickly depleted within a zone of 1 mm of the root, and does not move any further in soil. For nitrogen, the depletion zone is 10 mm from the root. The hyphae extend this depletion zone for phosphorous. These fungi increase soil stabilization. Tillage, monoculture, fungicides, and long fallows can deplete mycorrhizal populations.

Bacteria

Bacteria form the base of the soil food web. They degrade a broad range of organic materials, and some produce antibiotics. Bacteria are the most numerous organisms in soil and represent the highest diversity of species in soil. Their functional roles include nutrient cycling and immobilization and formation of humus. There are bacterial pathogens as well, which may produce allelopathic compounds that are toxic to plants. Because of the diversity of food sources used, rapid reproduction and small size, bacteria are very responsive to changing soil environments and critical players in both organic matter decomposition and nutrient cycling.

Bacteria can also form symbiotic relationships with plants. The primary example of this is the *Rhizobium* symbiosis responsible for nitrogen fixation in the roots of legumes. Legumes lacking the symbiotic relationship show signs of nitrogen deficiency when grown in low nitrogen soils, while nearby plants inoculated with the appropriate *Rhizobium* species do not.

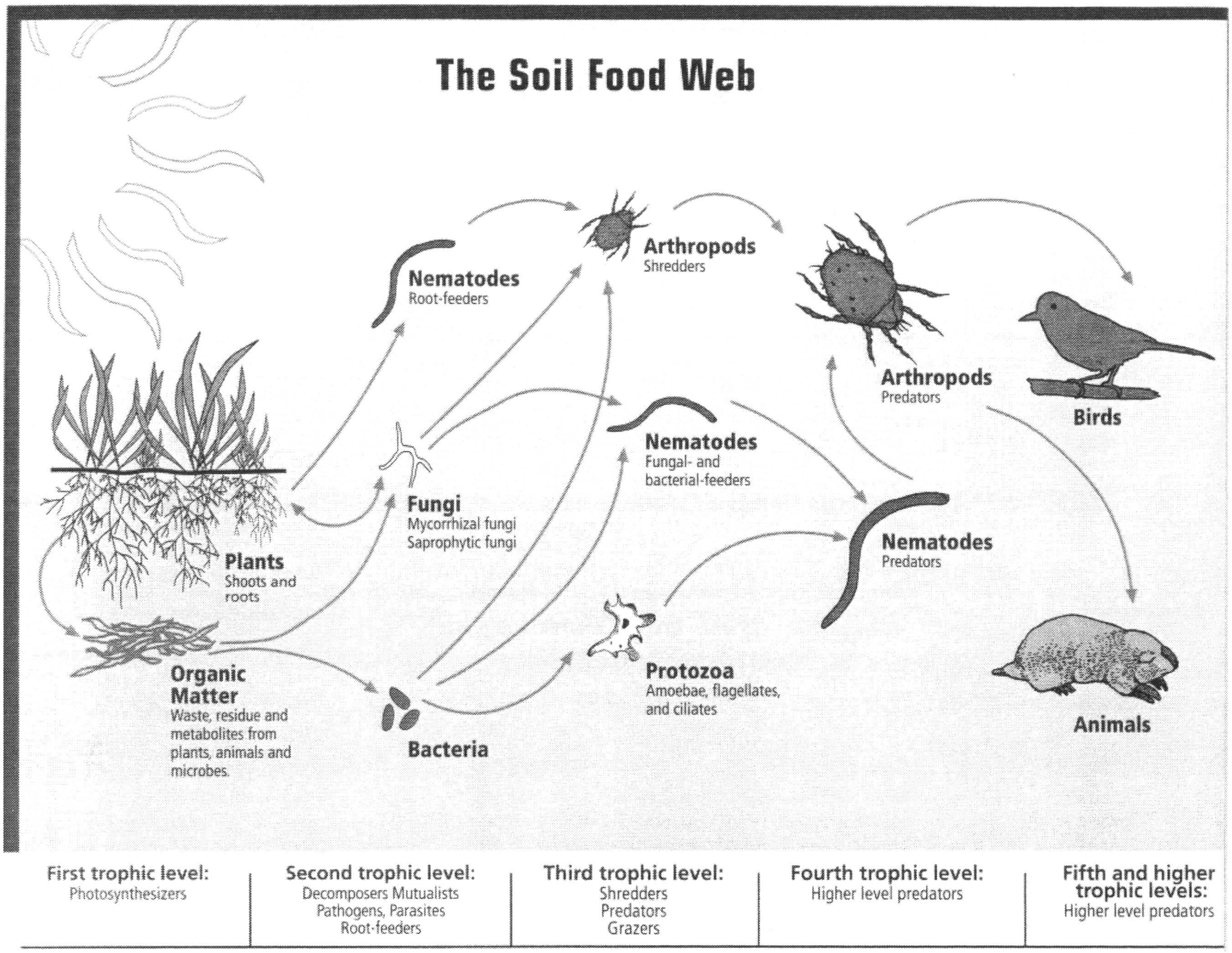

Figure 1
The soil food web
(Source: Soil Biology Primer. 2000. Soil Conservation Society, USDA Natural Resources Conservation Service)

The rhizosphere (root surface) is a "hotbed" of activity for bacteria, actinomycetes, and fungi. Plant roots exude or secrete carbohydrates that serve as food sources for a number of beneficial and pathogenic organisms. Roots that are colonized by beneficial organisms are less likely to be attacked by pathogens due to competition for nutrients, production of antibiotics, and/or parasitism of the pathogens by the beneficial organisms.

A strong food web is needed for optimal nutrient cycling and release. Research has shown that plants growing in sterilized soil produce less biomass than plants growing in soil where bacteria are present, which in turn produce less biomass than plants growing in soil where bacteria, fungi and higher order consumers are present. Regular additions of organic matter from diverse sources and avoidance of tillage practices and chemical applications that are detrimental to soil organisms will help maintain a diverse and strong soil food web on your farm.

Interpreting Soil Test Results and Estimating Nutrient Availability

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Soil quality is of major importance to crop health and productivity. Soil management practices should strive to protect soil from erosion, maintain or increase organic matter, provide an environment which promotes a diverse microbial population and create and maintain good soil tilth. A nutrient management program should: 1) supply sufficient nutrients to achieve the optimum yield that is realistic for the site; 2) avoid excess application of nutrients which can degrade water quality or which create imbalances causing lower yield and/or quality; and; 3) maintain desired soil pH, to ensure that all nutrients are readily available to the crop.

Physical properties of soil

Soil texture

Soils are composed of solid particles with spaces between them. The soil particles consist of tiny bits of minerals and organic matter The areas between them are called pore space and are filled with air and water. An agricultural soil should consist of about one-half soil particles and one-half pore space by volume. Ideally, organic matter will account for 5 to 8% of the weight of soil particles. Moisture content varies considerably with factors such as soil drainage and the amount and frequency of rain or irrigation. For most agricultural crops, conditions are best when the pore space is filled about equally with water and air.

Mineral soil particles are grouped according to size. Beginning with the smallest, they are classified as clays, silts, sands and gravel. Soils consist of mixtures of various size particles. **Texture** is the proportional amount of each of these groups. Note that the word *loam* does not refer to a specific group of particles, but is used to describe mixtures of sand, silt and clay. Soil texture is determined solely by the sizes of the mineral particles and has nothing to do with organic matter Weathering can change the size of these particles, but only over thousands or millions of years. For all practical purposes, the texture of the soil does not change.

Soil texture has a major effect on the physical and chemical characteristics of soil. Sandy soils have rather large particles and large pore spaces (macropores). Clay soils have very tiny particles with very small pore spaces (micropores), but because there are many times more pore spaces, clay soils have greater total pore space than sandy soils. Water adheres to soil particles. The force of this can pull water through a soil, even against gravity. This is called capillary action, and acts in the same way water is lifted in a straw or narrow tube. In this case, water is lifted farther in a narrow tube than in a wide one. Capillary action is greater in micro pores than in macro pores. However, if a soil is compacted, all water movement including capillary movement is limited. Clay soils absorb and retain more water than sandy soils, but are typically poorly drained and not well aerated. Sands are well drained as a rule, but retain little water. Loams combine some of the moisture retention characteristics of the clays with the aeration of the sands and are widely considered the best agricultural soils. Sandy soils are coarse-textured and are often referred to as "light" because they are easy to work. Clay soils are fine-textured and their particles will bond tightly together when they dry out after being wet. These soils can become very hard and difficult to work and are often called "heavy." The terms "heavy" and "light" do not refer to weight; sands actually weigh more per unit volume than clays.

Soil structure

Structure is another term used to describe physical attributes of soils. While texture refers to the sizes of mineral particles, structure is the overall arrangement or aggregation of soil particles. Terms such as loose, hard-packed, granular and cloddy are among those used to describe structure. Soil structure can be modified by activities such as tillage, moisture level, freezing and thawing, root growth, earthworms and other soil inhabiting animals, and driving or walking on the surface.

Very sandy soils nearly always have a loose structure and don't become hard-packed or cloddy. Fine-textured soils can become hard-packed. This condition interferes with root growth, inhibits movement of water into (infiltration) and through (percolation) the soil. The micro pores in fine textured soils can easily be filled with too much water to the exclusion of air, limiting the exchange of oxygen and carbon dioxide. The macropores of coarse-textured soils facilitate infiltration and percolation of water and the exchange of gases, but they retain little water for crop use. By loosening and aggregating a fine textured soil, we can improve water infiltration, percolation, and gas exchange, and still maintain the ability to retain water for plant growth. An aggregated soil consists of granules that resemble crumbs. A granule consists of many clay or silt particles clumped together. A well granulated soil has micropores within the granules and macropores between them and is both moisture retentive and well aerated.

Natural activities such as freezing and thawing and the movement of roots contribute to granulation of soils. Tillage at proper levels of soil moisture causes granulation. Excessive tillage in an effort to prepare a fine seed bed, especially when soils are dry, destroys soil aggregates. It is very easy to overwork a soil with a rototiller. Pounding from rain or irrigation water droplets can also destroy soil aggregates. Soils should be managed to create and maintain soil aggregates as much as possible. Mulches are an excellent way to protect aggregates from splashing water.

Biological activities are important to the granulation process. Earthworms pass soil through their digestive systems, adding viscous juices which bind particles together. Snails and other organisms leave a trail of slime behind them which acts as a glue. Organic matter is an important factor in the formation of soil aggregates and it adds greatly to their stability. Soil organic matter, particularly if it is well decomposed (humus) is a binding agent which holds clay particles together. It is believed that this is due to chemical unions between humus and clay particles. The end result is that soil organic matter plays a major role in granulation. By increasing the stability of soil aggregates, the soil becomes easier to work and doesn't compact as easily.

Organic matter not only improves the structure of fine-textured soils, but it is equally beneficial for coarse textured soils. Coarse soils have a high proportion of macropores, facilitating gas exchange and water movement. However, due to a low proportion of micropores, these soils are not moisture retentive. This makes frequent irrigation a necessity during dry periods. Organic matter substantially increases the proportion of micropores, greatly improving the water holding capacity of a coarse-textured soil. It is estimated that for each per cent of soil organic matter, moisture holding capacity is increased by as much as 16,000 gallons per acre in the root zone.

Chemical properties of soil

Information about a soil's chemical properties can be provided by a soil test. The soil test report indicates the levels of the nutrient elements that are available for crop nutrition. It also provides information about soil pH, buffer pH, cation exchange capacity, base saturation and organic matter. If this sounds a bit intimidating, the following discussion should be helpful.

Essential elements

There are thirteen mineral elements known to be essential for plant growth. All of these nutrients are absorbed from the soil. Six of these are called **major or macro** elements because the plant uses them in comparatively large amounts. They are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Sometimes Ca, Mg and S are referred to as secondary elements because they are used in somewhat smaller amounts than N, P and K. The other seven are called **minor, micro or trace** elements. These are every bit as important as major elements, but are used in very small amounts. These elements include iron (Fe), Manganese (Mn), zinc (Zn), boron (B), copper (Cu), molybdenum (Mo) and chlorine (Cl). Nickel (Ni) is accepted by many scientists as the 14^{th} nutrient element derived from soils. The level of crop production can be no greater than that allowed by the most limiting of the essential elements.

In addition to mineral elements, carbon (C), hydrogen (H) and oxygen (O) are essential elements. Plants take these elements from air and water. Although these elements are not applied as fertilizer materials, our soil management practices affect their availability.

Soil pH

One of the most important aspects of nutrient management is maintaining proper soil pH. Soil pH is a measure of soil acidity. A pH of 7.0 is neutral. If the pH is below 7.0, the soil is acid, but if it is above this level it is alkaline. Most soils in the Northeast are naturally acid and need to be limed periodically to neutralize excess acidity. Soil pH is important because it affects the availability of nutrient elements for plant uptake. Availability of macro-elements and molybdenum (Mo) is restricted in acid soils. Under alkaline conditions, with the exception of Mo, the availability of microelements is reduced. Under acid conditions, Ca and Mg are frequently low and there may be toxic levels of iron, aluminum and manganese. Most crops, do best when the soil pH is in the range of 6.0 to 6.8. At this pH, the availability of macro and micro elements is maximized, and accumulation of toxic elements is minimized. Although most soils in the Northeast are able to supply sufficient amounts of microelements, growers may find deficiencies in some of the sandy soils. A soil pH of 6.0 to 6.2 is more appropriate for these soils. Clearly, you cannot expect to achieve the benefits of other amendments when pH is suboptimum.

Cation exchange capacity

"Ions" are atoms or groups of atoms (molecules) which have an electrical charge. "Anions" have a negative ($^-$) charge and "cations" have a positive ($^+$) charge. Plants take up nutrients from the soil either as cations or anions. Many of the nutrient elements are cations (pronounced cat-eye-ons). These include Ca^{++}, Mg^{++}, K^+, Fe^{+++}, Mn^{++}, Zn^{++}, Cu^{++} and ammonium (NH_4^+) which is a form of N. Other cations of importance are H^+ and Al^{+++} (aluminum). Anions of importance include nitrate (NO3-), a highly leachable form of nitrogen.

Cations are attracted to negatively charged surfaces of small clay and organic (humus) particles called colloids. This attraction is called adsorption. Generally, cations are held tightly enough on adsorption sites to restrict their loss through leaching. These cations can move from the adsorption sites on colloids into the soil water solution and vise versa. In the soil solution, they are available for root uptake, but are also subject to leaching (see Figure 3). Cation exchange capacity (CEC) is a measure of the number of adsorption sites in a soil and is an important indicator of the soil's ability to retain and supply cations for plant use. CEC is reported as milli-equivalents per 100 grams of soil (meq/100 g). The CEC of agricultural soils ranges from below 5 in sandy soils with little organic matter to over 20 in certain clay soils and those high in organic matter. A soil with a low CEC has little ability to store nutrients and is susceptible to cation nutrient loss through leaching.

Cation exchange capacity is related to soil texture. Of the mineral particles, clay is the only group which makes a significant contribution to CEC. However, there are several types of clays, and they vary considerably in their CEC. Crops are grown on a wide range of soil types, including many that are sandy and low in clay. In many areas of the Northeast, the types of clay present have a low CEC. In much of the region's soils, organic matter is the primary contributor to CEC. This fact is true even of soils with low organic matter. Not only does organic matter improve the physical properties of soil, it also plays a vital role in soil chemistry by increasing CEC.

Base saturation

The cations Ca^{++}, Mg^{++}, K^{+} and H^{+} normally account for nearly all cations adsorbed on soil particles, although trace elements that are cations are also present in minute quantities. Ca^{++}, Mg^{++}, and K^{+} are base cations that raise soil pH and H^{+} and Al^{+++} are acidic cations that lower soil pH. If all of the adsorbed cations are bases and none are acidic, there would be a 100% base saturation, and the soil pH would be about 7 (neutral) or above. In acid soils there are acid cations present and the percent base saturation is less than 100. Besides having sufficient quantities of Ca, Mg and K, they should be in balance with each other because an excess of one of these can suppress the uptake of another. As a general rule a Ca:Mg:K ratio of about 20:4:1 is desirable. When expressed as percent base saturation, desired levels are: Ca 65-80%; Mg 5-15%; and K 2-5%.

Soil organic matter

As already noted, soil organic matter (SOM) improves moisture holding capacity of sandy soils, aeration of clay soils and helps overall structure of any soil. Soil organic matter is the chief contributor to cation exchange capacity in many soils and is an important factor in all soils. The break down or decomposition of SOM releases nutrients which can be used by plants. Organic matter is also food for organisms that are essential for a healthy soil environment.

By definition, organic matter contains carbon. Carbon is a source of energy for microorganisms (microbes) in the soil. These are microscopic plants and animals such as bacteria and fungi. Some of these are pathogens which cause plant disease, but in a healthy, well managed soil the vast majority are beneficial. Organic matter provides food for a diverse population of microbes in the soil and this helps prevent any one type of organism, such as a plant pathogen, from dominating.

Soil organic matter is continuously being produced and broken down by living plants and animals. Dr. Fred Magdoff of the University of Vermont coined an appropriate phrase: *There are three kinds of SOM; the living, the dead and the very dead.* The living fraction of the SOM is made up of living plants and animals, including microbes, that are found in the soil. When they die, stalks, leaves and other plant parts retain recognizable characteristics for a while. This is the dead fraction of the SOM. It is also called the active fraction because it supports microbial activity. Sooner or later the dead organic matter decays due to microbial activity and cannot be recognized for what it was and eventually becomes humus. This is very dead organic matter. It is also called inactive organic matter because it will no longer support microbial activity. In addition, animals eat plants or other animals and pass some of their food through their bodies as manure which is rich in nutrients and organic matter.

Organic matter consists of numerous compounds which vary greatly in their ease of decomposition. Sugars, starches and proteins are rapidly decomposed by microbes while lignin, fats and waxes are resistant to this process. Fresh organic residues consist mostly of easily decomposed compounds which break down rapidly under favorable conditions. The result is a rapid reduction of the volume of SOM. The resistant materials remain and form the dark colored material called humus. Humus continues to decompose, but at a very slow rate. Carbon dating has shown some humus to be thousands of years old. Humus forms the colloids which contribute to increased cation exchange capacity and good soil structure.

Soil organic matter is broken down by microbes as they consume it for food. Any factor that affects soil microbial activity also affects SOM break down. In the microbe, respiration combines most of the carbon from SOM with oxygen to form carbon dioxide gas. For this process to continue, there must be an exchange of oxygen and carbon dioxide between the atmosphere and the soil pore spaces. Gas exchange can be restricted if the soil is compacted or saturated with excess water. This slows the rate of SOM decomposition. While excess water inhibits decomposition, a certain amount is necessary to support microbes. Therefore, conditions of moisture stress can be expected to slow the decomposition of SOM.

Soil microbes are also influenced by soil pH and temperature. This is especially true of bacteria. Under acid conditions, bacterial activity in breaking down organic matter is greatly reduced. Soil fungi responsible for break down of SOM are generally less affected by low pH. In most cases, however, bacteria are responsible for most of the decomposition of SOM, and as a rule this process is markedly slowed if soil pH level drops below 6.0. The optimum soil temperatures for bacterial activity are in the 70 to 100° F range, but activity occurs as low as 40° F, although at greatly reduced rates.

A moist, warm, well aerated soil with a pH between six and seven provides ideal conditions for decomposition of SOM. These are the conditions that promote optimum growth of most crops. Productive farming practices can be quite destructive to SOM! This may seem frustrating if you are trying to build SOM, but decomposition is a beneficial process. It provides energy for a diverse group of soil microbes, releases nutrients for plant growth and produces humus. The challenge is to continuously replace what is lost and, if practical, increase SOM.

Adding to soil organic matter

Compost is an excellent source of organic matter that nearly all farmers can make. Most growers don't have enough raw materials to satisfy their needs. Some are bringing in additional materials such as municipal yard wastes to compost on site. Others are purchasing compost from the increasing number of commercial composters. Regardless of the source, compost should be finished before use. Finished compost has no recognizable bits of matter and will not heat up after turning. Compost should be tested for nutrient content. Most soil testing laboratories can test compost. Finished compost should have a low ammonium content, high nitrate level and a pH near neutral. Repeated use of a compost high in a particular element may cause a nutrient imbalance and result in excess levels of certain elements. This can easily be avoided by soil testing on a regular basis (at least every three years).

Animal manure is an excellent source of nutrients and organic matter. About half of the nitrogen in fresh dairy manure and 75% of the nitrogen in poultry manure is in the form of ammonia. Ammonia is subject to loss through volatilization if not incorporated immediately after spreading. In the soil, ammonia is converted to nitrate and is available for plant use. However, since nitrate is subject to leaching, large applications should generally be avoided. There are times when readily available nitrogen is needed, but fresh manure should be applied with caution. Many people prefer to compost manure before field application. This stabilizes the nitrogen. Manure can be mixed with other materials for composting. **There are strict certification requirements for composts that contain manure and there are required intervals between application of manure and harvest of edible crops. Check with an accredited certifying agency.**

Soil testing

Sampling a field

To collect a soil sample, use a soil probe, soil auger, or garden shovel to collect samples from throughout the field. Use a "V" or "W" pattern to ensure that the sample is representative of the field. Areas of the field that appear to be a different soil type, have been managed differently, or where you have observed poor growth, should be sampled separately.

Scrape away surface litter from the sites you choose, and then collect a core or slice of soil to the plow depth—usually about 6-8 inches. Collect cores from 10-15 different sites and place them in a plastic bucket. Mix these samples well, and then take about one pint of soil from this mixture to send to the lab. It is best to air dry this sample before you send it to the lab.

The report you receive from the lab should indicate soil nutrient levels of most of the macronutrients and some of the micronutrients, pH, and organic matter. Some labs also include cation exchange capacity, buffer pH or exchangeable acidity, and/or base saturation.

Adjusting pH

Lime is used to correct the pH of acid soils. The amount of lime needed depends on several factors, including current and desired pH, soil texture and soil organic matter. Soil testing laboratories measure soil pH, which is actually a measure of the concentration of H^+ in the soil solution. This is called active acidity. There is also H^+ adsorbed onto soil colloids. This is called reserve (or exchange) acidity and this is related to cation exchange capacity (CEC). When lime is added to the soil, reactions occur which result in H^+ being replaced by Ca^{++} and/or Mg^{++}. At the same pH, a soil with a high reserve acidity (loams, clays, high humus) may require 3 to 4 times as much lime as one with a low reserve acidity (sands, gravels). The soil testing laboratory uses a procedure to determine the lime requirement of a soil based on its reserve acidity. A buffer pH test is the most common method used to determine lime requirement, but some laboratories use other procedures.

The speed with which lime reacts in the soil is dependent on particle size and distribution in the soil. To determine fineness, lime particles are passed through sieves of various mesh sizes. A 10 mesh sieve has 10 openings per linear inch, or 100 openings per square inch (10 X 10) and a 100 mesh sieve has 10,000 openings per square inch (100 X 100). Lime particles that pass through a 100 mesh sieve are fine and react rapidly—within a few weeks. Coarser material in the 20 to 30 mesh range will react over a longer period such as one to two years or more. Agricultural ground limestone contains both coarse and fine particles. About half of a typical ground limestone consists of particles fine enough to react within a few weeks or months, but to be certain you should obtain a physical analysis from your supplier.

Super fine or pulverized lime is sometimes used for a quick fix because all of the particles are fine enough to react rapidly. Hydrated lime, "quick lime" are fast acting, but are not approved for use in organic systems because they are highly caustic.

For the most rapid results, lime should be thoroughly mixed with the soil. Plowing turns lime under to the plow depth, but does not mix it with the soil. Harrowing can do a good job of mixing, but generally only incorporates lime to a depth of two to three inches. A split application can be use in which half the lime is plowed under, and the remainder is applied after plowing and harrowed in. A rototiller is effective for soil incorporation. Weather permitting, it is best to apply lime when the soil is somewhat dry. If lime is spread on damp soils, it tends to cake and will not mix as well with soil particles. If the soil pH is already at a reasonable level and rapid results are not needed, lime may be recommended to maintain current levels. In this case plowing or simple harrowing are sufficient for incorporation.

Besides raising soil pH, lime is the most economical source of Ca and Mg for crop nutrition. Select liming materials based on Ca and Mg content with the aim of keeping these nutrients in balance. If the Mg level is low, a lime high in Mg (dolomite) should be used. If Mg is high and Ca is low, a lime high in calcium (calcite) is preferable. "High Mag" lime contains about 5% Mg and 35% Ca by weight. Use this if both Ca and Mg are needed. Continual use of one type of lime over several years can lead to an imbalance between Ca and Mg. Because dolomitic lime is the most readily available liming material in some areas, many growers have used it continuously. As a result, many fields are low in Ca and very high in Mg. Choose liming materials to achieve and maintain appropriate base saturation levels. Shop around for and insist on the appropriate material, even if you must pay for increased hauling costs. Gypsum may be used to increase Ca if calcite is not available, but it does not affect soil pH and is expensive.

The neutralizing power of lime is determined by its calcium carbonate equivalence (CCE), also referred to as Effective Neutralizing Value (ENV). Recommendations are based on an assumption that lime is pure calcium carbonate which has a CCE (ENV) of 100%. If lime has a lower CCE (ENV), more than the recommended amount is needed, but if it is higher, as with some dolomitic limes, less is required. To determine the amount of lime to apply, divide the recommended amount by the per cent calcium carbonate equivalence of the lime to be used and multiply by 100. For example, if the lime recommendation is 2 tons per acre and the lime has a CCE of 72%, apply 2.7 tons per acre according to the following calculation:

$$\frac{\text{recommended amount X 100\%}}{\text{CCE}} = \text{amount needed}$$

OR

$$\frac{\text{2 tons/A X 100\%}}{\text{72\%}} = \text{2.7 tons/A}$$

Wood ashes can also be used to raise soil pH. The calcium carbonate equivalence of wood ashes varies considerably, typically ranging from 30 to 50%. They are chemically similar to quick lime and supply K as well as Ca and Mg. **CAUTION:** Do not over-apply wood ashes. Wood ashes spread in a concentrated area cause the soil pH to become extremely high, inhibiting plant growth.

On some soils, it may be necessary to lower the pH. Elemental sulfur can be used for this purpose. Like limestone, particle size and thoroughness of mixing affect the speed of reaction. It typically requires six months to a year to lower pH to the desirable range. The ability of sulfur to lower pH varies among soils. Sulfur must be oxidized to be acidifying. This process is carried out by certain bacteria. If they are not present in the soil, this reaction, and hence, acidification will not occur.

Nutrient management

Macronutrients

Nitrogen

Nitrogen is often the most limiting nutrient. Deficiency symptoms include yellow plants and stunted, weak growth. The majority of crops absorb most of their nitrogen in the nitrate (NO_3^-) form, but they can absorb some ammonium (NH_4^+). Unfortunately, nitrate-nitrogen is very soluble and is easily leached. In most soils, a considerable amount of nitrogen is tied up in organic matter (crop residues, soil organic matter, microbes, etc.) not immediately available to plants. This nitrogen must be released by microbes as they consume organic matter. This process is called mineralization These microbes are most active when the soil is warm, moisture and aeration are optimum and pH is 6.0 or above. Cool conditions, dry or waterlogged soils, low pH or compaction will slow the conversion of nitrogen to available forms. Under favorable conditions, we can usually expect from 20 to 40 lbs. of nitrogen per acre for each per cent soil organic matter.

Nitrogen uptake varies from as little as 50 lb./A for snap beans to 200 lb/A or more for field corn. Soil organic matter can provide some and in some cases all of a crop's need for nitrogen. The rest can be provided by adding an organic fertilizer. Manure can supply a substantial amount of readily available nitrogen. For safety reasons and to meet certification requirements, a minimum time interval is required between application of non-composted manure and harvest of edible crops.

Phosphorus

Phosphorus, like nitrogen, can be found in organic and inorganic portions of the soil. P deficiency appears as a purpling of leaf tissue. P is found in three forms in soil; two of which are unavailable to plants. The unavailable forms include P in organic matter and phosphorus fixed or bound to iron and aluminum at low pH, and calcium and magnesium at high pH. Added fertilizer phosphorus is fixed with other elements and is only very slowly made available. Since this is a chemical reaction, it is faster in warmer soils than in cooler soils. Banding P with a material such as bone meal, rather than broadcasting, is a more efficient way to apply this nutrient if needed. Manure is a good source of easily available P.

Potassium

Potassium is the third of the "primary elements." Crops deficient in K can suffer considerable loss in yield or quality without showing obvious symptoms. This is often called *hidden hunger.* In severe cases, leaf edges may be scorched. Plants absorb potassium in the ion form K+. Potassium can be leached from sandy or gravelly soils of low CEC and be fixed and unavailable in some clays.

Calcium

Calcium is absorbed by roots in the ion form Ca^{++}. Deficiency symptoms include young leaves that are stunted, distorted and spotted and necrotic at the leaf edge. Blossom-end rot is seen in tomatoes and other fruiting crops. Although calcium may be present in high levels in the soil, dry conditions will limit its uptake by plants and cause deficiency symptoms. High levels of sodium, K, Mg, and ammonium may also cause deficiency by interfering with Ca uptake.

Magnesium

Magnesium is absorbed in the Mg^{++} form. Deficiencies appear on older leaves as regions between leaf veins which become yellow and sometimes a reddish color progressing to **brown**. Deficiency is most common on acid, highly leached soils or those that are high in potassium or calcium.

Sulfur

Sulfur is cycled through soil in a very complex fashion, similar to nitrogen. In the northeast, significant quantities of sulfur are supplied by air pollution. Deficiency symptoms, while rare, first appear as a yellowing of the younger leaves (as compared to older leaves with nitrogen). Sulfur deficiency is more likely in acid, sandy soils, low in organic matter.

Micronutrients

Micronutrients are not often deficient. Deficiencies are more likely in soils with high pH or sandy soils with low organic matter. Some of the more common elemental deficiencies are mentioned below.

Iron deficiency

Iron deficiency appears as a white or yellow area between the veins of youngest leaves. It is most commonly seen on soils with higher pH and can often be worsened by liming. Excess P can tie up some iron as well.

Manganese deficiency

Manganese deficiency can result in yellowing of the interveinal areas of young leaves (as compared to older leaves for magnesium). It is most common on soils with pH above 6.8.

Zinc deficiency

Zinc deficiency often shows as small, abnormally shaped leaves and stunted plants. As with iron, excess P can tie up zinc.

Boron deficiency

Boron deficiency may result in browned, distorted, brittle plants. Fruit may be affected by cracks, necrotic spots, and internal breakdown. Stems of cruciferous crops may be hollow. It may occur on alkaline, highly leached, or low organic matter soils. Caution: some crops are sensitive to high levels of boron; don't apply more than two lb per acre. Solubor or boraxo are approved sources for organic agriculture.

Determining what nutrients to add and how much

The only way to know the nutrient needs of a soil is by testing. Guess work is dangerous. There are numerous examples of fields with serious nutrient imbalances and excesses where they were not monitored by soil testing. Most soil test reports indicate nutrient levels in terms of parts per million (ppm) or pounds per acre (lb/A). This is not usually very helpful to a grower, but the report also has a rating of low, medium, high (optimum) and very high (excessive). These ratings are useful in determining the need for nutrient applications.

Generally, it is best to have nutrient levels in the high/ optimum range. This means that for most crops, there is an adequate supply of nutrients. If a nutrient is in the medium range, it is likely to limit crop production, but not severely. In such cases, crops can be expected to respond to application of the nutrient some extent. If a nutrient level is in the low range it is likely that it will limit production to a greater extent. In this situation, increasing the level of the nutrient element will probably benefit the crop significantly. Conversely, if a nutrient is in the very high/excessive range, it may interfere with the availability of certain other nutrients which are otherwise in adequate supply. Excess levels of nitrogen and phosphorous also create potential hazards to water quality, and in the case of nitrate-nitrogen in drinking water, can have serious health effects.

One of the goals of a soil management program should be to maintain nutrient levels in the high/ optimum range. If a nutrient is in or is approaching the very high/excessive range, it should not applied until the level drops back into the high/optimum range. This is challenging for organic growers, because many amendments such as compost contain a number of different nutrients. If a material is used, it may supply some needed nutrients, but may also increase the level of nutrients already in excess. Also, many materials are slow to release nutrients and may continue to do so after levels are in the very high/excess range. The best way to avoid excess nutrient levels is to test the soil regularly and be aware that many materials will continue to increase soil nutrient levels for some period of years after application.

Pre-sidedress soil nitrate test

The pre-sidedress soil nitrate test (PSNT) was originally developed to improve nitrogen management in field corn on farms with a significant amount of manure usage. It has been adapted for use in vegetable crops to predict the need for applying supplemental nitrogen during the growing season. Regular soil tests performed in the fall, winter or spring do not provide an accurate indication of nitrogen levels in the soil during the growing season. The PSNT can also be a useful tool for organic growers to monitor nitrogen levels during the summer, when this nutrient is normally at its highest levels. This allows the grower to adjust applications of nitrogen containing amendments, such as compost to avoid excesses of deficiencies. A nitrate-nitrogen level of 30 ppm measured in early summer is believed to be adequate for most crops. Levels above 50 ppm are considered excessive.

To sample for the PSNT, collect 15 to 20 subsamples from the top 12 inches of soil about one week before the pumpkin vines begin to run. Mix the subsamples and retain about one cup full for the test. Soil samples should be spread on a nonporous surface to air dry soon after sampling. Follow the general directions for collecting soil samples described on page 10 in this chapter. When the soil is dry, send your sample to a soil testing lab for a nitrate-nitrogen test.

Organic fertilizers

Nutrients need to be added to fields to replace those which have been removed by harvesting. If a soil is low in a nutrient(s), extra effort is needed to achieve suitable levels for optimum production. Organic fertilizers include animal manures, compost, green manures, and other natural materials. Many of these are slow to become available to plants, but contribute to soil fertility in the long run. Some are available more rapidly and are useful to correct a problem or to supply certain nutrients while fertility is built up with other amendments. Some common organic fertilizers are listed in **Table 1** along with typical nutrient values and relative availability. The list of allowed inputs sometimes changes, so it is important to consult with an accredited organic certifying agency to determine what fertilizer materials are currently allowed.

Organic fertilizers often improve soil organic matter and generally have a positive impact on soil tilth. They are easy on earthworms and microbial populations. However it is possible to achieve excess levels of some nutrients if some amendments are applied at high rates over a period of time. This can be avoided by monitoring levels by regular soil testing.

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Table 1
Organic Fertilizers. Check with certifying agent on current status.

Material	N (%)	P_2O_5 (%)	K_2O (%)	Relative Availability
Alfalfa pellets	3	0.5	3	slow
Dried blood	13	2	0.5	med/rapid
Bone meal (raw)	2-6	15-27	0	slow/med
Bone meal (steamed)	.5-4	18-34	0	slow/med
Cocoa shells	1-2	1	2-3	slow
Compost (unfortified)	1-3	.5-1	1-2	slow
Compost (fortified blends)	3-5	3-4	3-5	slow/med
Cottonseed meal	6	2	2	slow/med
Fish emulsion	4-5	1-2	1-2	rapid
Bat guano	6	9	2	med
Manure (fresh) dairy	.5	.2	.5	med/rapid
horse	.6	.2	.5	med
sheep	1	.3	1	med/rapid
poultry	1-3	1-2	.5-2	med/rapid
Pumace (fresh apple)	6-7	1-2	.2	slow
Soybean meal	6-7	1-2	2	slow/med
Tankage (dry)	6-7	10-14	0	med
Wood ashes	0	1-2	3-7	rapid
Colloidal phosphate	0	18-25	0	slow; about 3% available
Granite dust	0	0	3-5	very slow
Greensand	0	0	4-9	very slow
Rock phosphate	0	20-32	0	slow; about 2% available
Sodium (Chilian) nitrate	16	0	0	rapid
Sul-Po-Mag	0	0	22	rapid; also contains Mg and
S				
Epsom salts	0	0	0	10% Mg-rapid

Nutrient content varies with origin and handling; availability depends on fineness of grind.

Tillage Practices for Maintaining Soil Quality

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Healthy soil is the foundation of sustainable crop production. It is the result of a combination of factors. While this presentation will focus mostly on how tillage affects soil health I first want to briefly go over the "bigger picture" of soil health.

A key concept for managing soil health is recognizing the interaction between the biological, chemical, and physical aspects of soil. **Biologically** healthy soil has low pest populations, or the ability to suppress pests, and is fully functional with respect to nutrient cycling and producing plant growth promoting compounds. From the **chemical** perspective, healthy soil has adequate levels of available nutrients, but not so high that there will be a lot of leaching; an optimal pH for the planned crop rotation; and low levels of toxic or disruptive substances such as heavy metals, aluminum, or salts. The **physical** characteristics of healthy soil include good tilth, water infiltration, aeration, and water retention.

The biological, chemical and physical properties mutually influence each other, and if we ignore one, the other will be affected. For example, aggregation of soil particles is influenced by the types of cations (e.g. Ca, Mg, K) and amount of organic matter present in the soil. The types of organisms present can be influenced by compaction and availability of food sources, and soil drainage influences the amount of nitrogen available to plants because saturated soil can lose nitrogen through denitrification, and well drained soil can lose nitrogen through leaching. In the past decades, agriculture has too much focused on the chemical aspects of soils and insufficient attention has been given to the physical and biological (especially) functions.

The key management approaches that can positively influence soil health are organic matter additions, reduced tillage, and compaction prevention. Adding organic matter to the soil increases biological activity and diversity, which in turn releases plant-available nutrients and holds them in the soil, increases soil aggregation, pore structure, and tilth, produces humus and other plant growth promoting substances, and reduces soilborne diseases and parasitic nematodes (Fig. 1). At least one long term cropping experiment has shown a yield increases related to increasing organic matter levels, especially in dry years when higher organic matter levels can improve water retention.

Now we'll move on to tillage. One question we can ask ourselves is why we till in the first place. The plow, which was invented in the England in the mid-1700s, revolutionized agriculture. It provided unprecedented control of weeds, allowed for a more stable food supply, and was a critical tool in the development of virgin lands in North America. Plowing the soil incorporates residue from the previous crop, weeds, and amendments. It's the first step in seedbed preparation, increases the conversion of organic matter to plant-

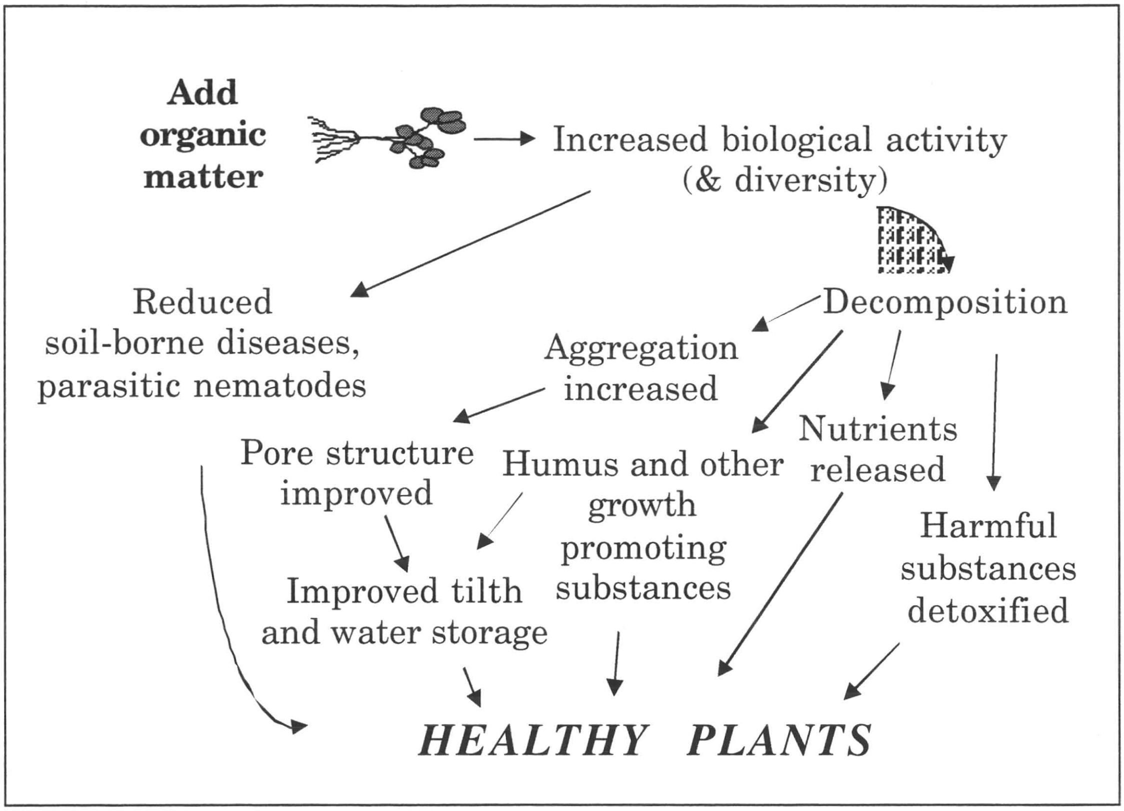

Figure 1

available nutrients, and reduces compaction, at least temporarily. So, the first experience with the plow was very positive, mainly because the destructive qualities didn't manifest themselves until after several decades.

In that respect, it is interesting to study the contributions of the eighteenth-century English agriculturalist Jethro Tull. Tull made an everlasting contribution to the worlds by inventing the seed drill, as he recognized that good seed placement improved germination and plant population over the conventional broadcast seeding (of small grains). Now, we recognize that the mechanical seeder is an essential agricultural tool, especially for conservation farming because no-till planters allow us to place seeds with very minimal tillage. Tull, however, also appears to have done an unintentional disservice to the land. He believed that plant roots absorbed nutrients as tiny soil particles (rather than as ions as was established in the following century). He therefore tilled his soils over and again to pulverize it. Sure enough, he was able to feed his crops for many years without the use of manure or other forms of fertilizer. But what was he doing? He oxidized the soil organic matter and released nutrients for his crops. In time, however, he mined the soil of its nutrients and food source for soil organisms. In the long run this is not sustainable, and we have seen similar problems with modern farming methods. One interesting lesson learned from Tull's work is that short-term research does not always provide the right picture.

There are also other negative aspects of plowing. It uses a large amount of energy, and repeated plowing destroys soil aggregates, which increases compaction and the potential for crusting, resulting in low water infiltration, increased erosion, and the development of a zone of low microbial activity near the soil surface. Intensive soil tillage exposes the soil to the elements and causes temperature and heat extremes near the surface, creating an environment that is uninhabitable for soil organisms. In that respect, we need to start changing our somewhat romantic image of clean tillage, which we often associate with goodness and tradition. What could be better than a beautiful, aromatic freshly-plowed field? In fact, we are actually doing something very unnatural, because soil is not naturally exposed to the elements and we are creating an ecologically unfavorable soil environment. A field covered with residues may not have the aesthetics of a plowed field, but it is a lot more ecologically compatible. Farm ugly, as they say.

Another factor associated with increased soil degradation is driving heavy farm equipment on a field. The weight of heavy equipment is concentrated in a small area underneath the tires, and can certainly increase soil compaction, especially if the soil is wet. The level of compaction is greater and extends deeper into wet soil than into dry soil, reminding us of the importance of staying off fields when the soil is wet.

The notions of water availability and compaction are brought together in the concept of the "optimum water range." Highly compacted soil has a smaller optimum water range than a well-structured soil (Fig. 2). During wet periods, compacted soils experience prolonged water saturation and aeration problems, because they do not have the large pores that readily drain and allow air into it. When the soil dries, compacted soils more readily experience drought stress, which is actually caused by hard soil not allowing for root penetration. So crops growing on compacted soil are "happy" only when the moisture conditions are "average." During prolonged dry or wet periods, however, the plants quickly become stressed and have decreased yield or quality. A well-structured soil will not show drought or aeration problems unless the conditions are very extreme.

So how do we improve soil health? First, we have to recognize that some soils have become "addicted" to tillage. Depletion of organic matter over time has resulted in soils that are so compacted that multiple passes are needed to break up clods to create a good seedbed. The relief is only temporary, however, as these soils usually settle back down and form crusts after the first good rain, inhibiting seedling emergence and root growth. What can we do to remediate such soils or prevent them from occurring in the first place?

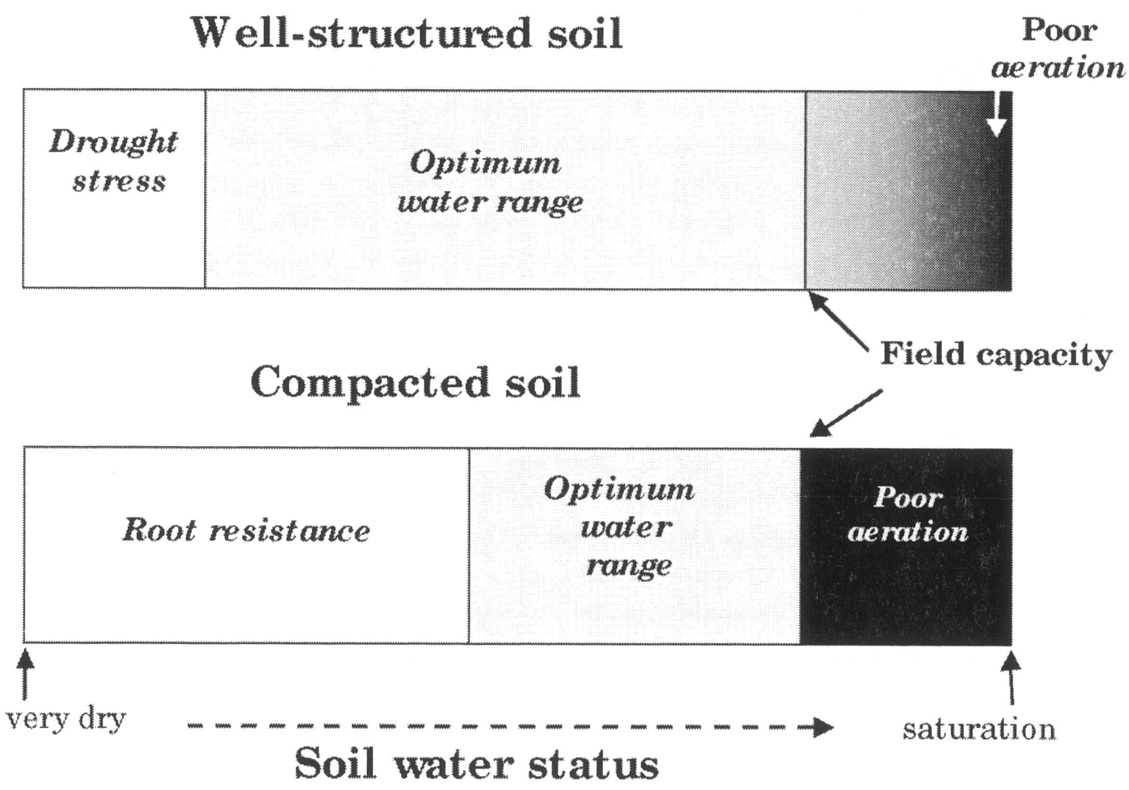

Figure 2

Building Healthy Soils

In general, the following practices will help build soils:

1. Organic Matter Management

- Add organic matter to the soil regularly.
- Use different types of organic materials.
- Use different sources of organic materials
- Reduce organic matter losses
- Keep soil surface covered with living vegetation as much as possible

2. Improved tillage

- Minimize tillage intensity
- Optimize timing
- Maximize surface cover

3. Minimize soil compaction

- No traffic on wet soils (by far most important)
- Minimize soil loading by reducing equipment weight and spreading the load with multiple axles and large tires
- Use controlled traffic lanes, and take advantage of ridges and beds

Reducing tillage results in many changes in the soil including higher carbon (organic matter) levels, better structure, better water availability, more biological activity, and reduced erosion.

Other changes to keep in mind are that soils may also stay cool later in the spring, nutrients may become stratified (higher levels near the surface) because they are not being mixed into the soil profile, and the pH of the surface soil will change more rapidly after applications of lime because the lime is not being mixed with a larger amount of soil.

There is a range of options for reduced tillage, including no-till, strip till, ridge till, and zone till. The cooler soils associated with no-till can be a challenge in the Northeast. Strip, zone, and ridge till are adaptations of no-till that can overcome some of the cool soil problems. The narrow tilled zone warms up faster due to the removal of a small amount of residue, and is loosened and aerated, creating more favorable conditions for germination and growth. My research program has shown that no till is most successful when used with crop rotations rather than in monoculture. Also, we found that using ridges or beds, which force controlled traffic, are very attractive for our climate conditions, especially on medium and fine-textured soils. No-tillage is generally very successful on sandy and gravelly soils, which have less compaction problems and are more drought sensitive.

We have learned that a good no-till seeder is a critical piece of equipment, because it allows for good seed placement under a range of conditions. Many times, farmers perform intensive tillage just to create a seedbed, while fine tilth is only needed in the soil immediately surrounding the seed. With a no-till or zone-till planter, tillage options are much more flexible. If serious cover cropping is part of the management of the farm, a no-till drill is essential. There should be no tillage prior to cover crop seeding, because that mostly negates its benefits. Recent studies conducted in Michigan suggest that even when cover crops or manure are used in a rotation, soil organic matter levels don't increase when a moldboard plow is used for tillage. Tillage practices such as no-till, zone-till, strip-till, and ridge-till do result in an increase in organic matter, even when cover crops are not used. In other words, the less the soil is disturbed, exposing organic matter to the air, the less organic matter is oxidized and lost to the atmosphere.

Mulching is another practice that can benefit soil health by providing cover for the surface of the soil and providing a source of organic matter. The use of mulches enhances water availability by improving infiltration into the soil and reducing evaporation from the soil. Mulching provides weed control by shading the soil surface and inhibiting weed germination, reduces splashing of soil and disease inoculum onto leaves and fruit, and reduces infestations of certain insects (i.e. Colorado potato beetle) on plants grown in a mulch system. Also, the temperature and moisture moderation from a covered soil promotes biological activity.

While bringing cut mulch into a field is feasible on a small scale, a different approach is needed for using mulch on a larger scale. Steve Groff, an innovative farmer in southern Pennsylvania has adapted a technique for planting into standing mulch that was developed by USDA researchers. Steve uses a no-till seeder or transplanter to establish a crop into the mulch from a killed rye/vetch cover crop that was planted in the fall of the previous growing season. The cover crop is killed either with herbicides or by a piece of equipment that rolls down and crimps the cover crop just as it starts to flower. You can learn more about this technique from Steve's web site: <HTTP://WWW.CEDARMEADOWFARM.COM/>.

What type of tillage makes the most sense on any particular farm? It depends…on the type of operation, the soil types, and the climate. What works for one grower in one part of the state may not work for another grower in another part of the state. Choose a system that is most efficient in terms of energy use and passes across the field, can handle organic matter additions in the forms available to you, and is appropriate for your management style and operation. Be aware that a there is often a yield reduction that lasts 2-3 years when changing to minimal tillage systems on unhealthy, degraded soils. Start small and develop a system that works for you before using it on your entire farm.

A good resource for learning more about soil health is: *Building Soils for Better Crops* by Fred Magdoff and Harold van Es. It's available from the Sustainable Agriculture Network, <HTTP://WWW.SARE.ORG/>.

Compost and Cover Crops for Organic Vegetable Growers

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Applying compost and growing cover crops are excellent practices for growers to use to enhance soil fertility. They improve the soil's nutrient, physical, and biological status.

Improving soil with compost

If one starts with a depleted soil, the first thing to do is to correct the pH with lime if necessary, and then add compost to boost overall nutrient levels and biological activity. This initial boost of compost is generally put on at a high rate of 10 tons per acre or more. Uncomposted manure can be used in a similar way, observing the time to harvest restrictions required by organic certifiers.

Composts made from different feed stocks can have widely different analyses. Chicken manure has very high relative phosphorous levels, since chickens are fed large amounts of grain, which is relatively high in P. Therefore, compost made with large amounts of chicken manure is also relatively high in P. Poultry manure composts generally have higher nitrogen-phosphorous-potassium (N-P-K) percentages than composts made from other feedstocks, some as high as 5-5-5. Conversely, composts made mostly with plant matter may have an analysis below 1-1-1. If you purchase compost, get an analysis from your supplier so you know what levels of nutrients you are applying to your fields. Otherwise, have a sample of your compost or manure analyzed at a lab.

A few years (perhaps 3-5) of heavy, but diminishing compost applications will bring soil nutrient levels up into the "high" range, even under heavy cropping. Crops remove far fewer nutrients than will have been applied. A ton of compost may contain 10 to 60 or more pounds of nitrogen, of which around half will be in available form. It may also carry similar amounts of phosphorous and potassium, along with calcium, magnesium, sulfur, and trace minerals. An application of ten tons per acre of compost with a 1-1-1 analysis, then, may add something like 200-200-200 pounds of NPK. An average vegetable crop harvest might remove on the order of only 80-20-100 pounds from the field. So, 120-180-100 pounds per acre may have been applied in excess of what the crop harvest removed.

Since P and K are mostly held by the soil, it is easy to see how they can build up to high levels after a few years of heavy compost applications. Nitrogen is a different story. It is easily lost to air or groundwater and builds up more slowly. So even after the heavy nutrient applications of these first few years, nitrogen will still be needed each year for most crops. P and K will be in ample supply. The soil fertility strategy can shift at this time, so the N comes mostly from legume green manure crops, and compost is used far less frequently.

Legumes for nitrogen

Tilling under heavy stands of legume green manure crops such as clovers or hairy vetch, can add over 100 lbs./A of nitrogen to the soil. The nitrogen content of a legume cover crop is roughly proportional to its dry weight content. This, in turn, depends in part on how much growing time the cover crop has had. In some cases, red clover may occupy a field for a whole year, but heavy crops of some cool-season legume crops, notably hairy vetch and field peas, can be grown before or after partial-season vegetable crops like lettuce, spinach, herbs, brassicas, onions, carrots, etc.

Another way of squeezing in a legume green manure is to underseed it into a standing vegetable crop at the final cultivation. For instance, red clover can be dribbled between rows of fall brassicas about a month after transplanting. By the time of harvest, the red clover will form a low mat over most of the field. It will have competed little with the crop, unless conditions became very dry. In that case, extra irrigation will have been necessary. By the following May, a good stand of clover will put on enough growth to supply the N needed by the next crop.

Cover crops and green manures

Legume cover crops include clovers, alfalfa, field peas, hairy vetch, field fava beans, sweet clover, soybeans, cowpeas, etc. The clovers and alfalfa are perennial sod crops, while the others are grown as annuals in different parts of the season. Mixes of legumes and grasses often give the best overall results. Tried and true examples are rye and hairy vetch; oats, triticale, and field peas; and timothy and alfalfa or clover.

Two outstanding references on cover crops are the *Northeast Cover Crop Handbook,* by Marianne Sarrantonio (1994), and *Managing Cover Crops Profitably,* by the Sustainable Agriculture Network, 2nd ed. (1998).

Crop rotation

During and after the first years of organic management, a good crop rotation needs to be put in place. The rotation is the key organic practice that allows pests, including weeds, to be controlled *and* soil fertility to be properly managed. Successful organic farmers realize the importance of their crop rotations.

The crop rotation can be seen as an organized succession of crops grown over the seasons on a given field. It varies from farm to farm, depending on markets, soils, and many other factors. Good crop rotations, however, include a fairly wide variety of crops. In addition to vegetable crops for sale, an effective rotation further includes green manure and cover crops, and possibly even grains and sod crops.

Vegetable crops tend to reduce soil quality, since their culture usually requires bare ground over much of the season, repeated trips across the field, and they leave little residue. Sod crops, on the other hand, cover the soil completely and provide heavy biomass when turned under. Over the years, a sod will raise soil quality to its maximum potential. Cover crops and grain crops fall between these two extremes, in terms of effects on soil quality.

Sample simplified vegetable rotations:

1. Intensive: Veg/cover crop → veg → veg/cover crop → (repeat) →
2. Extensive: Veg/small grain → small grain/hay → hay (legume and grass sod) → veg/cover crop → (repeat) →

In the first example, a vegetable crop is grown every year, while in the second, there are two vegetable crops in every four years. Since vegetable crops are generally worth far more than grain, hay, or cover crops, the first rotation would seem to be more remunerative than the second. However, pest and weed problems are almost guaranteed to be worse in rotation 1, requiring far more effort and expense. So rotation 2, in fact, may make the grower more money. Anne and Eric Nordell of Beech Grove, PA have taken this extensive vegetable rotation idea to a very high level.

From a soil fertility standpoint, rotation 2 is also easier to manage. The cover crop used in rotation 1 will often be cereal rye, since rye can be planted late in the season, allowing for late vegetable harvest. Since rye is not a legume, it supplies no extra nitrogen to the field. Nitrogen must be added the following year for good yields, so most growers put on additional compost. As we will see below, on a continuing basis this will result in excess applications of P and K (and perhaps other minerals as well). Soil nutrients will gradually but continually build up in rotation 1. Also, the soil physical condition will be degraded by "lack of rest" from constant vegetable production. This will further increase the need for compost.

Rotation 2, however, allows for improvement of soil quality with a sod crop, and plenty of nitrogen from the sod plowdown. Other nutrients can be held at stable levels. In fact, if need be, P and K can be removed from this system by harvesting hay off the field. Little compost needs to be added into this rotation to maintain overall nutrient levels and soil fertility.

Organic matter levels can be high in either rotation 1 or 2. But rotation 1 will require continual additions of compost to keep them high. Over 20 years or more of production, P and K levels will become very high in rotation 1, but will remain fairly stable in rotation 2 if hay is removed from the field.

Other rotations can be designed that combine or alter various aspects of these samples, and may incorporate many of the wide variety of cover crops for nitrogen fixation and weed, insect, or disease control.

Phosphorous and potassium

Are very high P and K levels a problem? Let's start with phosphorous. Fifty years ago, soil phosphorous levels were typically low enough to reduce yields unless extra P was applied, so farmers said, "the more P, the merrier!" But after years of P applications, many agricultural soils now have high or very high P levels. Compost, especially poultry compost, is extra high in P, so this attitude no longer applies. When soil P levels get very high, small amounts of P will leach into groundwater and, in the long run, degrade lakes and ponds. This is not good stewardship, even though the overall phosphorous pollution contribution from organic vegetable farms is small. Soil high in organic matter is less "nutrient leaky" than those whose OM is low. But eventually levels can build so high that losses will be significant. Adding excessive nutrients is also wasteful. In other words, it is not a good sustainable practice.

Oddly enough, even when soil P is in the "high" range, it is possible that some crops on some soils can be P-deficient under cool conditions. The crops will grow out of that deficient state when the soil warms. My suggestion would be to use row covers and other means to warm the plants and the soil if you want really early crops, and soil P will not be a problem.

Potassium is another issue. It can also leach into the groundwater, but is not considered a problem pollutant like phosphorous. However, very high K levels may interfere with plant uptake of other cations like calcium or magnesium. The science gets fuzzy in this area, but soil organisms may also not be getting what they need under very high K conditions. If your soil tests show continually increasing K levels, that also raises a warning flag.

Contaminants

Another aspect of yearly applications of compost that needs scrutiny is that of contaminants in the compost. Sewage sludge composts are not allowed for organic production, in part because of heavy metal contamination. But this can be a problem in other composts as well. Some dairy and sheep farms use copper sulfate foot baths to reduce foot rot diseases. Compost from these farms has shown high copper levels. Non-organic broiler chicken operations routinely feed arsenic-based coccidiosis control compounds as well. Yearly applications of such contaminated composts could lead to undesirable soil levels of these heavy metals. Be sure to review analyses of the compost you use for heavy metal content.

In conclusion

To sum up, I suggest that poor fields can benefit from heavy compost or manure applications for a few years. Once soil nutrient levels and biological activity are increased to high levels, a diverse rotation including vegetables, sod and cover crops has many benefits and avoids nutrient overloading problems.

Soil and Nutrient Management Practices on Upingill Farm

Transcript of a presentation by:

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I don't have very many slides today; usually I bring too many. Also this is the first time I have ever been asked to talk on this subject. I think 90 percent of my talks are always on strawberries and they generally center around weed control, so it is kind of nice to have to think of something else to talk to you folks about. We will sort of plod through the pictures and I think by comparison to what I picked up out of Jean-Paul's and what else has gone on here today, my talk will be very anecdotal on this subject.

In general, I would have to say that much of our farm is branded as certified organic, but I have never considered myself an "organic farmer." I consider myself much more a traditionalist in the sense that the part of the world that I come from, I come from a family of farmers that have always been farmers. It just has never gone out of our family. What has happened in my life is largely just a large part of chance.

The land I farm is very typical of New England. You will see from most of these photos that it is almost like we are in the middle of a rain forest the way the forest has crept back in around the edges of the field. Because so few people keep animals anymore, all the marginal land has just gone back to woods. All of the land that we farm is probably class-I and class-II soil.

As it just happens to us, most of the land that we farm due to our climate being in New England we get all of this lake effect snow which becomes lake effect rain in the summertime and then we also get hurricane season that blows up from the coast. So, unless you are on exceptionally well drained land in the Connecticut Valley, at least for me anyway, since I am not on the really well drained stuff, I generally have too much water in my environment.

Also, the soils I am working primarily are silt loams, at least all of our level land where we do most of our crop production. Our biggest single crop is strawberries. It wasn't what I had intended when I first went for my first career which was a chef. I decided that my farm was going to have three main enterprises all integrated in a really nice way. We were going to grow wheat, raise my bees and I was going to have small livestock, basically sheep. I was never going to have anything more than sheep and chickens. I spent my teenage years chasing my father's cattle around the county and I never wanted to see another cow on my farm. As you will see as you go through this all of this has changed because really the way you were raised and what is in your genes I guess probably just tends to keep coming back to you.

This is a typical soil, typical field of ours with our biggest crop. We basically keep about five acres of strawberries in production and we have two types of production on the farm. We have our strawberry production and we have our vegetable production. In one sense for years I have been trying to get out of vegetable production because of the low capital input it is almost where every farmer starts in our neck of the woods—with organic vegetable production. There is a lot of heavy price competition from people who haven't been in business and don't really know what it is costing them to be in business.

After a few years in the vegetable business one day I went to my cousin's strawberry operation to pick strawberries and I went from being a leek farmer to a strawberry farmer in about twenty minutes of picking strawberries in his field and seeing hundreds of people coming to pick his strawberries for him and do his work for him I decided that that lonely work I was doing out in the middle of all that mud in November with those leeks was for the birds. It just wasn't making it for me. I was in physical therapy for my back. Lots of stuff just wasn't happening right.

We started with the berries big time in the early 90s and I really think the demographics in the strawberry you-pick is only going to get better as the population ages. You can see from these first few slides, after I go through my introduction of my farming, I am going to go into some of our strawberry cultural practices. I don't have a lot of vegetable slides because since I always do strawberry talks, I have lots of strawberry slides, but I do have some of our vegetable stuff.

Our vegetable stuff is primarily field type things that we do now for our farm stand to decorate it in the fall. The bees have stuck with our operation. They are a real integral part of it. Partly because honey and bees have such a good image. What we are endeavoring is to get out of the certified organic trap that we are basically in as not being a big grower, we still need third party certification because a lot of our produce gets shipped to Vermont. There are some co-ops up there, but basically once our own retail business at our own farm is going well enough we hopefully can drop that oversight thing and just do things that we want to do. Having the bees on the farm and as a honey sales person it just acts as a really good all over thing with the public. It has good image. Not only that, I end up using some cover crops that probably some people tend to avoid.

We grow a lot of buckwheat because it gets us through the summer dearth on nectar in our cover cropping program. Also, it makes use of the clover and stuff that we grow that we intercrop with all the rye that we grow for mulching the berries and stuff like that. We make sure that the bees are standing right on the hillside at the farm.

We grow a lot of vine crops as you can see. Our biggest vine crop is not so much squashes, which are for our own stand in the fall, we grow a pretty good size melon crop. Primarily musk melons, but we are also growing watermelons, regular cantaloupes and some other exotic melons because now that our brand name is established with our melons in these markets we can offer a whole line of things and the melons kind of are paying the payroll for the summer labor that we need in our berries.

We have a lot of things happening on the farm at this point. One of the reasons we got into bees was that we had no land and bees don't really respect the boundaries that everyone else has so the bees basically would do a fly over and bring back a crop for us.

When we first moved into the county my wife and I were both working in the city and we decided that we had to change our lifestyle and for raising our children. We were living between Boston and Providence. I worked in Providence, she worked in Boston and we split between the two and we saw each other kind of when we put the children in one another's arms. We decided to leave that and come back to the small farm that she had grown up on. It wasn't a farm when she grew up on it, it was just a hobby farm where they raised some horses. We started out with that and started renting little pieces of land around the town and then finally we got well enough established that people would trust us with a little bit bigger piece of land. I come from a farming family and basically I ended up selling farms in that town and using them as a land swap arrangement to eventually buy a bigger farm.

So, what we will go over when we get into the soil fertility management thing is what is happening as we start with the resource management of that farm trying to incorporate traditional stuff with that. What we started farming for was a better way to raise our children. That was our primary mission with our farm. That is kind of how the cattle have come into the picture. Part of me rediscovering that cows weren't so bad, but also that I don't like feeding my children dairy product that we found in the store. I don't believe that a homogenized milk product is at all healthy for you as well as the other stuff, plus I have always wanted to make cheese.

My grandfather was an international grand champion breeder of Ayshire cattle from 1930 to 1950. When I went out shopping for cattle, I naturally explored whether or not I could get some stock that would trace back to the time when my parents and my heritage ruled the roost in that breed. We had our first Ayshire calf just this past year. My little son that came along rather late in life glommed right on to it. Of course the calf is growing a lot faster than him and he can not handle it now, but that's all right. There you can see the start of our Ayshire herd with the other calf that was born this year.

You can see where our farm is situated. Those are the hives right between the cows up on the hillside. Our ultimate plan for this farm is that we will have horned cattle grazing on the hillside to sell that cheese at the farm stand. My plan is that ultimately we will keep doing vine crops, vegetable crops and potato crops for a fall farm stand along with raspberries that we are getting into and then the cheese is basically my winter operation as I am growing older. I find as I am getting in to my 50s that the field work that I used to do out in the sun just isn't the greatest anymore. Hopefully, I am going to turn that over to people who are younger than myself and think it is a lot of fun.

This year we started putting in a food processing plant in the farm to sell more value added berries and other value added products to make my cheese in and to handle the milk and stuff. That will keep me busy during the winter. I have always had to shift gears throughout my career. It is no different now. Now I am going back to constantly try and remember all that stuff that my parents used to talk about with the cattle and they're gone. I don't have them to ask the questions of.

The other thing that we are doing is raising pastured poultry. It is always nice on a hot day in the summer time to start slaughtering chickens. All of these things work in. Our compost piles are basically fancy manure piles. They will range in everything from potatoes to some feed corn that may have gotten moldy with a large component of cattle manure and bedding all just put in a heap until it is has been steaming for awhile and once the action has quieted down it becomes safe to put on the fields. The pastured poultry has been a project to get other people involved on the farm. This woman works for me, but this is sort of like the old share cropping situation. I will give you space to raise your chickens if you feed or help to sell them. She manages the front of the farm during the you-pick time. It has also been good for my daughter. It has been one of her big projects. Believe it or not raising chickens can land you a $30,000 scholarship. She won a total scholarship to go to college with. One of the kickers when we were at this luncheon that they had, the chairman of the search committee comes up to her and says, "Oh, you're the women who raises her own chickens." She has been involved with Vicki doing this throughout. Vicki and I had always done the eviscerating and slaughtering and she does kind of the day to day management of the birds. She finally got to really get her hands into the operation with us, too. But, it is all part of what I think our farm is really about which is basically creating a good way to raise our children.

I still use conventional tillage. It is part of my traditional attitude. It is kind of the only thing I know. It is also what I have and what I started out with. I try to be good about it in terms of field passes, etc. We generally try to do our plowing and our harrowing in one pass by using a clod-buster following the plow so that we don't go back and re-harrow. We use pretty much the same method whether it is melons or potatoes, the only difference in the next shot is we prepare raised beds for most of our stuff because our soils tend to be very heavy and we have more than adequate rain fall. This is an alluvial deposit. There is a 20-foot drop between this deposit and its drainage basin. Our biggest problem in terms of structural fertility is generally too much water and not enough air and soil life created from that. So, most of our stuff we put into some sort of raised bed. We do all of our melons into raised beds.

We have traditionally used plastic mulch on melons and a lot of our vine crops. What we are going to now is doing a living mulch, but what we have been experimenting with is putting down our plastic in the fall. Putting down compost or manure in the fall and then laying the plastic right on top of that. We would have already previously drilled in rye. The rye comes up within the lanes in the spring and all we do instead of having to add mulch at that point is basically roll the rye down. It has worked out to be a nice system. We are also taking it to the point which we are going to try this year in our field where we do not take up the plastic and we are going to try making it go another cycle because the rye was interseeded with clover and that clover is now what is coming up between the lanes in that plastic.

Our basic method is if we have to correct any nutrient levels at this point we probably would have done it through a broadcast application. Generally, we find with most of our soils that we almost always need to have an addition of potassium and our cheapest and most convenient thing to apply for that is Sul-po-mag. We are able to get that for about $225 per ton. It goes on nice. It does a good job for potassium sulfate and we generally put that on with our clover covers, etc. The strawberries in their establishment have a relatively low nitrogen requirement, which is kind of a nice thing for our key crop.

Also, as it ends up for us, in most research on strawberries you can't make them phosphorous deficient. Most of our soils always test phosphorous deficient. Even on soils where we have gotten our organic matter approaching five percent we have started to have some good indications of available phosphorous already there. Our silty loam soils, the way it is explained to me, that the phosphorous is there it is just hidden between the particles and it is not available. So, we are generally on phosphorous deficient soil which is the other reason why the berries are a good thing in our estimation with our soil. So, basically a broadcast application and then we make these ridges. If this was going to be a potato field, our potato planter does pretty much the same thing. We try to keep everything on the same system so that it can all be managed accordingly.

After we have created the ridges, we primarily use Wilson cultivators. We also use these for bed formation as well, but we use basically the same system for hilling our potatoes or cultivating between things, etc. It is our main piece of cultivating equipment. On our soils what works for us is keeping everything up on these ridges. The only place where we do not do this in on the hillside slope that you are going to see in a little bit. This piece of land is Hartland silt loam. We grow potatoes on this land. This particular piece of land fell prey to a practice of previous farmers of always putting lime on their manure when they were spreading manure on their fields. The pH in this field was running like 7.5-8.0 which is kind of high for most of the crops that we like to grow.

A sideline that we were doing on this land that I don't think is worth doing is we got involved in an experiment. I don't know if you are familiar with "re-mineralize the earth" or not. Over on the side there is a pile of stuff with which we are involved in an experiment with some researchers at U-Mass and some people for *The Publication for Remineralizing the Earth*. What their thought was is that soils that have been farmed a long time had been depleted of a lot of their trace minerals. There are several big quarrying operations in our valley and a grant writer got the idea that we should take some of these mineral wastes from these gravel operations and see what would be the affect of adding these minerals to the soils. There were two types of stuff available. This was trap rock dust from the crushing of stones that they use primarily as schist whose key ingredient is calcium. We have that stuff available to us and then we have the float from a gravel operation where when they are washing gravel there will be all of these minerals that they want to wash out and then that becomes a waste product and they have all this cloudy stuff with minerals at the construction pit for you to go pick up for free. People were using that in the area also.

These researchers asked me if I would help them out. We used this in various ways and it actually did work very well against Botrytis in strawberries. But as far as raising the brix level of the fruit by applying this to the soil, no it will never happen. We applied it to grain crops instead of our cover crops. We did not get any results. The hypothesis was disproved. It is an interesting thing in terms of soil fertility. If you do have a quarry in your area that does crush rock and you can get it, what is nice about it is that most of our soils also kind of have a little bit too much magnesium in them. The Lee lime that they get in the Berkshires is a high magnesium lime and that is generally what is available in our area. Actually as a source for calcium without excess magnesium, different rock powders like this from various quarries do come in handy. This one had high calcium and would help buffer the soil's pH but it did not add the excess magnesium.

The other thing in terms of approaching our fertility, especially with the strawberries and the other cash crops we rotate with strawberries is leeks. I can't look at just my fertility as a single issue. I will not put any animal manures and especially my own compost stuff on this land where I am going to grow berries or leeks. We rely primarily on plant cover crops and then the additions of things like Sul-po-mag or black rock phosphate and pure minerals like that.

We have also gone to making all of our own straw because anytime we have bought straw it is almost like going out and paying for somebody else's problems. We have introduced a lot of really nice German chamomile with New York State wheat straw into our fields at different times. You just create a lot of nightmares with that. Basically, 60 lbs of nitrogen per acre for the total vegetative year of this crop. That is not hard to make at all. We are planting at usually about 14,000 – 28,000 plants per acre. We do a delayed planting to help aid with our weed control in these and the crop just ahead of this was the rye cover crop. We almost always precede our strawberries with sudan grass the season before that. After that land is seeded with sudan grass we will go through seasons of clover on the land before it is replanted to leeks. We will generally follow leeks and strawberries back and forth. This is one of the few things that I don't think does anything bad to my strawberries. If I can get sweet corn, we are currently going in to having sweet corn at our farm stand. If we can get sweet corn to be weed free we will probably grow that ahead of strawberries also because as a relative of corn, etc. it would not vector anything bad to our berries.

The addition of the rye straw is probably the single biggest source of organic matter. We are putting down an incredible amount of straw. We are putting out at least six tons to the acre every single year. The plants are there for at least two to three years besides everything else that we have plowed into the land. The production of our rye straw is a major undertaking every year. We are probably putting in at least 10-15 acres into the barn of rye straw every year. As one of our biggest crops and work activity, what we do is plant the rye in late August, September, October all the way up to November if we can and we basically interseed most of our rye, almost all of it with red clover. After we mow the rye in the spring we do not go back and have to do any tillage. The clover will come on. Hairy vetch does not recover from the mowing – it never seems to come back. I don't know why, it just doesn't. To me is seems like it should, the red clover will always come back.

The farm has two major resources, the one 14 acre flat field that you see going in the center field of the photo and there is another 10 acre field that we are contour farming which is where I am standing taking this photo from. I am standing in the middle of the alfalfa field that was there when we bought the farm. Alfalfa, orchard grass with a lot of quack grass by the time we got it.

The 14 acre field is two types of soil. There is a Raynham silt loam which is at the lowest parts of it and it has a Hartland silt loam in the upper part and the Hartland ranges out into some Merrimac at the extreme headland of the field. The Merrimac is a really fine soil for doing organic production on because it is one of those extremely sandy soils. The Hartland silt loam is real nice on this and it is the upper part there and that is were we are putting all the berries. Our first year with this field to get it started we did that center strip which you see plowed up the center of it. The upper half of that was the first place that we planted strawberries. That piece of land had been in continuous silage corn for about 15 years. The organic matter tested out in that field at five percent organic matter content. The farmer that I bought it from was a traditional guy with a lot of cattle and huge equipment to really put down a lot of manure. Our first year growing rye on that – the rye at the end of May, early June was up to about eight foot high and the stalks were so thick on it that the equipment could not handle the stuff.

The fertility on the field was incredible from this management, but the weed problems in it were also unbelievable in terms of everything that had been put on it. Every kind of broadleaf chemical had been used on the land and an entirely new family of weeds is always waiting for you each year. The years that we have been bringing this farm out of that kind of production to make it fit for growing strawberries has been a long hard climb.

This slide shows that whole center strip – those berries are now out of production and plowed under. We would have disked them over as soon as we were finished harvesting them in July. This is basically August/September when we are getting ready to sow our rye. You can see on the right hand part of the middle field just below that black section, that is one of the fields that we cut rye off of and it is basically all clover for the summer period before we plow it under again and plant rye on it. Just ahead of that you see two white strips going back and that is part of our buckwheat. I like to plant buckwheat. When I am first getting onto a piece of land I generally plant buckwheat on it just to assess what the land can do. If there is any part where buckwheat doesn't grow there probably is some kind of a serious problem. The headlands in this field would not grow buckwheat. There had been so much traffic for years of harvesting the silage and the plowing patterns of the field that the entire headlands at the further end of that piece would not grow buckwheat because of the soil compaction and also because there was a slope at the end that was bringing too much water into that part of the field. Between diverting it and growing various crops on it and going over it lightly we are now growing on that part of the field. There were a couple acres at the headland of that field that weren't productive because of water and compaction and serious problems with that.

Over on the left you see a strip that went through our micro-cropping pattern which was to grow buckwheat to assess what it would do. I can generally get three crops of buckwheat into a piece of land in a single year, if I can, out of a single sowing before I plant rye on it for the winter. Rye or winter barley, either one. I will put on winter barley if it is quick enough. We have to get it planted before the first of October. We can't really get a good stand of barley in our latitude if we put it on later than that. Anything later than that has to be rye.

The winter barley is a great feed for cattle, for pigs, sheep and any kind of waterfowl love it and most fowl love it also. There are a few dietary things you have to watch because it is very abrasive to the gut. You either have to soak it or grind it or something, but it is a marvelous feed and it is pretty easy to grow. It threshes out nice. There again a straw from that I generally will sell to someone else after we thresh out the straw because it will be too weedy for putting back on our land. What we like to grow is basically rye hay. We thresh out virtually none of the rye. We harvest it in early June when it is just headed up and once it is mowed it is dead and then the clover can come on in the field.

The center brown spot, where those stripes of white are growing is where we took out the planting of strawberries and we will probably put you-pick peas in this strip next year because when we are up there picking berries people will get a hold of that.

The other thing on this farm is on this slope that you are looking at that we have planted, the upper part is still in alfalfa that will get plowed down next year and we will put field corn for grain on the top of the hill. There is a strip of sweet corn and then there are strips of sorghum and then there is buckwheat at the bottom. There is also a strip of pumpkins in this contour also.

Now this backs up to part of our strawberry rotation you can see the buckwheat growing. As soon as we disked off those strawberries I usually put buckwheat on as a smother crop for weeds during the summer. There are still some berries in there that we are probably going to try taking to a third year fruiting in that back piece and this is the group of berries that we just planted this year. That land before the berries were planted had buckwheat on it for two years with rye covers in the meantime. Last year it had a crop of sudan grass with cowpeas and other things on it that we plowed down. The rye was on it right before we planted it and that is the other reason for our delayed planting because we will take the rye off and then do our planting.

Generally, what we have been using with the demise of Agway is they had a lot of fertilizers that they bought when they wanted to get into the organic production business and I did a pretty sizable purchase of a chicken fertilizer that they had put together. It includes everything from manure to chickens, body parts and everything that they manufactured to sell to organic farms. With their bankruptcy there was a big stock of this at the local fertilizer plant that I bought up. We have bought that and used it for top dressing in things like our renovated strawberries, this was 6-6-6. In our renovation of strawberries if our nitrogen levels are low we go out and buy it in some form like that.

We have not had good luck on berries doing things like using alfalfa meal and soy. We have done that in years when all of a sudden there was a problem. I am not sure exactly what was going on in those fields where we used a feed ingredient as a fertilizer, but I never had such problems with a crop as I had when I used that and I can't explain why. The plants were anemic and it came on suddenly. Tissue samples showed nothing. We had no nutrient imbalances of the major things, anyway, but they just weren't thriving. It is possible it could have a seasonal thing. It was kind of a cold, wet season. But, it was the only thing I had done differently from anything that I had ever done with berries before. We had other berry plantings on the farm that were doing fine but the field were we put our combination of soy meal and Sul-po-mag, because they were the only things that would match organic certification that the local fertilizer mill could put together for the planting and because they had run out of what they had that was NOFA approved and so they made that up for us. We applied that and used that as the fertilizer. Broadcast, did our hilling and usual things and then halfway through the season, basically when it was time for them to run and vegetate they just stopped. There were no nematode problems, there weren't any of those other things that there should have been and that was the only thing I changed in my management. This is back in the days when we used to raise several acres of leeks. The same soil, this is our key crop that we like to integrate with our berries if we are going to grow another cash crop on the land with them and work in as a rotation this is my preferred thing with that.

We irrigate on our land primarily for frost control where we very seldom have to put down water for water sake. It is usually not necessary. We have had one or two seasons where I have watered crops for fear of losing it to drought. Generally, if we are watering we are either evaporative cooling which we will do on potatoes a lot, especially in the summer. Potatoes like to be cooled down in the afternoon. They don't like hot days they like to go in to the night cool. We will water at midday on strawberries for evaporative cooling and then this past year we got to spend many sleepless nights watering all night long to keep things from freezing. That is winter barley in the foreground of the photograph. This is probably just immediately after setting plants and we are watering them in once they have been set in the raised beds on there. The only place we really do not do that creation of the ridge is on that contour.

This farm as you can see from this wet area that is running right through the center of the field were there is a lot of hazel wood growing etc. In terms of what it points out to there, saturated soils like that in a low spot are virtually used as grazing land. There really is nothing you can do with them in tillage. They are better off as a resource just left. Even grazing them at the extreme banks is a problem. Then the strip going up the hill, the lower part of that strip we used for vine crops and then each edge of the contour on it, basically on the left edge we are raising raspberries, we have a perennial crop that does not require any tillage. Because it is a small part of the field it would be difficult to be turning a tractor in and around. We plan to do pastured poultry also on that section, putting the poultry in amongst the raspberries on that as a way of keeping weeds down and putting stuff right back in to the land.

You can see a crop of sudan grass and above that you can see the corn. Next year where that sudan grass and corn are will be re-seeded into rye and red clover over the winter and then where the alfalfa is at the top will be plowed down next year and field corn will go in up there. This is another shot of the same thing except, I don't know how evident it is to you, but the key things we have had to do on this farm is the drainage. The drainage ditches that were in it are all filled in. It is our biggest thing. Soil that is holding too much water has no life in it. That strip of buckwheat is for a new planting of raspberries next year. We broke the sod on that hillside two years ago, put it to rye and the following year it was in a summer crop of buckwheat and next year it will be civilized enough and the sod broken out that we can put raspberries in there.

I am happy to take a question at this point of anyone has one.

Questions and answers

Q: I find that rye can be a problem to handle. How do you manage it for the least problems?

A: Likewise with you I have had rye in all kinds of forms. The worse problem with combined rye is that it has too much rye seed still in it. Most growers will not reset the concaves and get the grain out of it. It is a pretty small seed so you end up with tons of rye seed and rye since it doesn't winter kill like oats or something like that is nasty stuff to have as mulch if it is really rye straw.

The other problem with rye if you use combined rye is that they don't thresh it until late July or August. It takes a really long time for the seed to get to the point where they can combine it. Generally, you have a lot of other weeds in the field. Unless they are using a really good herbicide management plan on it most rye straw will be infested with weeds and more rye. My experience lately has been, like with this field that has had so much high fertility and grows such rank rye that my machinery can't handle, I cut it fairly early. You cut it as early as you can when you have the weather in your side. At our latitude basically from May 30th on if there is enough crop in the field to make a crop for you as far as what you want, cut the stuff. The earlier you cut it the less weed seed you are going to have. As soon as it heads up. If the head has formed it will not regrow. You can wait until the cuticle on the leaf dries down if you want a stalk on it, but the other thing you have to worry about is if you let it get too high.

If you take rye that is grown to eight foot and on really good land rye will get up to eight foot high with no problem, by the time that goes through a hay baler, unless you have got a chopper, you go to shake the stuff out you are going to have strands like this that you are trying to put down around stuff. It will be a very poor mulch. It won't keep any of your weeds out either. I used to mow it myself with a disk. I have a disk mower. Now I pay the farmer next door, who since the local straw dealer went out of business the dairy farmer next door had taken to growing rye and selling it. As he is cutting his rye I have him cut it with a discbine. He has a flail conditioner after his mower which pulverizes the stock so it dries better. We have a chopper that chops it. We put all of our rye through a bale chopper. We have a trailer with a chopper mounted on the front. We load the trailer with about 40-50 bales and the chopper is out in front and we just throw whole bales into it and it chops it up. The rye hay is no problem. That is one advantage that combining has is the extra between having gone through a combine and then going through a baler you could generally hand shake it out and it is not bad. The rye hay is really nice if you have a chopper to do it. We flail condition it. The other thing you can do to make it easier to handle is let it get rained on a few times. Don't worry about it, let the stuff get rained on it will help break the cuticle down on it. Just rake it again, dry it out again and then bale the stuff. Your baler will probably handle it a lot better, too. Because it is so waxy, most balers, unless they have straw tuckers, the baler can't handle the stuff. It goes through too fast and it is a weird adjustment you have to make on a hay baler to handle that stuff, but most people who bale straw have special bale retarders in their balers to handle a waxy cuticle. I know that is kind of an essay answer to what you thought was simple question.

Q: Why do you use rye if it's so tricky to manage?

A: A couple of things about it. Number one the rye is cheap. Rye is going to run you about $9 to $12 for 50-100 weight, depending on how you are buying it and it is untreated seed they do not put any work into it.

Compared to other species, most other species of cereal grains they have developed have very low amounts of straw and very high amounts of grain. Most of the rye we plant as cover crop is still primitive in that respect and has a massive amount of straw compared to the amount of grain in it. The barely that you saw in that other shot, if we get a couple of tons of straw off an acre we would be doing really good where as we can probably get six tons off any acre of rye easily. Because it is just that much more product in straw compared to the grain species. Most of the wheat that you see growing out in this part of the world, I guess it is actually called Geneva, which is the principle soft wheat grown in much of the northeast now. The stuff doesn't even get to two feet high and it has these huge seed heads on it. It is a very highly bred plant. It is bred for grain it is not bred for producing straw.

Plus the rye will also germinate. No matter how late you are in your management you can put that stuff on in the middle of November and it can make a catch. It is a really remarkable plant. The other thing that we do with it is the rye was planted on this contour and you can see that it is gone now. We have our rye down on our berries. We put these guys out on it, too and they were making a remarkable amount of milk on it. It is really incredible how much milk they make on a bin of rye.

Q: Do you have any problems with pests?

A: We have a lot of problems in our organic berries with strawberry rootworm, it is our biggest pest.

For tarnished plant bugs I can tell you what not to do. We do scouting and we put in a lot of traps for capturing them. Don't leave rye standing or any weediness or aging plant near them. I'll relate the worst experience we had with tarnished plant bugs this past year. I left a strip of rye standing near a stretch of strawberries, hopefully to act as a windbreak and create a nice little microclimate to boost those berries along because they were a late variety and I wanted them quicker. We never had such an infiltration of tarnished plant bugs as we did in a patch of strawberries with a wintered over crop like that left standing beside them. It just was an enormous pest gatherer.

Q: Are you sure it was the rye?

A: Well it could have been chance because also there is a strip of rye between them and a hay field and the hay field also could act as basically a reservoir for tarnished plant bugs, the hay field had alfalfa and other species that tarnished plant bugs like and I have tried putting reservoirs of alfalfa near strawberries but tarnished plant bugs just love that little white blossom they will always come over and get some.

Just as well we have to watch for tarnished plant bugs whenever we are using row covers because the row cover will boost their populations also. They like being under that row cover it helps them out just like it helps the berries out. They are a major problem. Cold is your best asset against them. Early fruit doesn't get bothered by them as much as all of your late varieties. Jewels, Late Glows and all those things and there is very few effective organically approved pesticides that will be effective on tarnished plant bug.

We do not have any problems with root weevil. The strawberry rootworms we can't really live with. I have tried various management strategies and I thought I had figured it out, but this past year I got another infestation after having gotten rid of them for awhile. I look at that as a syndrome. Usually we get a strawberry rootworm problem whenever I damage some roots on some strawberries and in this case I hit them kind of hard with some cultivators when we were renovating. It was a dry time and it was just this one section I did not feel like resetting the irrigation to irrigate this one little patch and those stressed plants got a patch of strawberry root worms in them who have proceeded to try to take over more than I think that they have any right to have.

Q: What varieties of strawberries do you use?

A: This is supposed to be soil fertility and it turned into another strawberry lecture. What varieties of strawberries, for what?

The way you can always tell the ones that are good for production are they are usually the ones that are the lowest price in the nurseryman's catalog because they have been around the longest and growers have bought them the most.

I am always kind of a "contrarian" and I always was buying more exotic ones and pricier ones and I never had such good luck as when I bent back to getting something like Honeyoyes which are a good New York State development. They are the most productive strawberry I grow or that I think anybody can grow. They are a good sturdy plant. They are not good when they get over ripe, but they have amazing production. They're a good plant maker because in strawberries for organic production the key thing that you are going to want to do is be on a nice light friable soil that you can do a lot of hoeing.

Unlike most other things, to get strawberries established in a weed free way, if you want to get a couple years production on them. They are really devilish on weeds. Strawberries don't mind other plants they have no bad will against any other plant. They think that growing in the edge of the woods in a bunch of weeds is just where they belong. They appreciate the shade that they get from other plants. The only way being able to counter their whole thing for organic production is to increase their planting density so that they are shading one another and keeping each other cool because that is what they really like. They like nice cool roots. I don't know how people get them to survive in plastic. I have never seen strawberries that I thought looked happy growing in that stuff. Nice well drained soil that can be cool like a north slope. If you have a nicely drained north slope and you have eradicated the perennial weeds in it to some degree something like Honeyoye.

Honeyoye is a really nice berry, but in strawberries it is going to depend a lot on your marketing and how you are selling them as far as what will go well. Honeyoye is a good all over berry. Cavendish works really good for you-pick operation, but it does have some white fruit problems. The only ones I would probably tend to avoid for organic operations are anything that is sensitive to leaf spot. You probably should avoid these because even the copper based fungicides which are the only thing you really have in an organic management program to fight leaf spot with are extremely toxic to strawberries. They just don't like copper. If you have bad leaf spot on a plant and you're not able to control that fungus, if leaf spot gets onto the calyx it makes very unattractive fruit; nobody buys it. They don't care how organic it is. They'll hop over that fruit with the damaged calyx, won't sell in anybody's market compared to something with a nice looking calyx. So a Midway would be one to avoid in that respect.

In conclusion

I have arranged this one as the last slide as far as the cows out grazing on the cover crop. It is incredible with them. I had always been told by my father that rye would make the milk stink and not to graze your cattle on it. You couldn't keep them off of this stuff. They would wait at the gate and would much rather be out there shuffling through the snow than eating something else and the milk didn't stink and the butter was extremely yellow.

Soil and Nutrient Management Practices on Roxbury Farm

Transcript of a presentation by:

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I caution you that everything you heard today you will hear again in a different way. So hang in there, there will be some repeats, but hopefully some practical application on what you already heard by the other speakers. I noticed some different approaches on fertility management here and there. For example, Harold differentiates three qualities in determining soil fertility. I distinguish one more, and I make the case for a fourth quality, which is called structural fertility. I see this as a quality that in itself needs to be recognized.

Let me walk you through these four different qualities one by one. I will start with chemical fertility.

Chemical fertility

I realize we mostly concentrate on vegetables, but I like to mention that when maintaining the chemical fertility of our land, the hayfields are usually much more self-sufficient than the vegetable fields. I think this is an important thing to notice.

But first let us look at the composition of different fertilizers. I gave you a handout (pages 45–56 in this proceedings). By the way, there is no way that I will be able to cover this handout in one hour, which is about eight pages printed in a very small font type.

What I like to point out in the first slide is the analysis on one of the tables of our own compost made from dairy manure. The same table is also in your handouts. As you can see here compost is a much drier product than animal manure, and you can compare the numbers as far as nitrogen, phosphorus, and potassium. Since the compost is made from cow manure, they are relatively comparable. The numbers go up a little bit when made into compost. The number that is considerably higher in compost than in manure is the organic and the dry matter, which I think is fascinating. I always wondered about how the dry matter can contain so much more than organic matter, but I just have to believe the analysis. What you have to realize with the nitrogen in the compost, is that it all consists of nitrates, while the eleven pounds of nitrogen in the solid cow manure is half ammonia and half nitrates. I also have some numbers here of pigs, chickens and horses.

The other thing I wanted to point out is that the poultry manure analysis shows high phosphorus levels. When you look at the needs and fertility requirements for vegetables' development, its needs for phosphorus are kind of low, so we don't really need poultry manure and in general we could be quite happy with compost made from cow manure coming from animals that have not been fed grains. High phosphorus manure comes from the very high grain diet animals consume. So, you will see phosphorus numbers go down for an animal that is being fed less grain and lives mostly on a diet of grass and hay.

Physical fertility

I was in the interesting situation that I had to look for a new piece of land. This is interesting from the perspective of assessing land for its physical fertility. I had to put myself in the shoes of a new farmer. What do you do when you look for land? The first thing I did was obtaining a soil map from the soil and water conservation service. It shows you where all the good land is in your county, in my case Columbia County. Those soil maps showed that a lot of good land, all the class-I and class-II soils, are located in Kinderhook. What are class-I and class-II soils? It tells you how they behave, but it does not always mean that they are suitable for vegetables. Some of these class-I soils are actually flood plains and frequent flooding does not go well with growing vegetables.

One of the most important aspects of a physical quality of a soil to be suitable for vegetables is that it has to have a high carrying capacity. In other words the ability to drive your tractors on them. When one inch of rain or more doesn't prevent you a day or two later to get back on there. With a clay soil you are not be able to do that. You have a very narrow window to get on there with your tractors – it can drive you crazy. Another aspect is good drainage and is related to the first. You also have to have good access to irrigation water, and a good deep A-horizon or what we generally call the topsoil. These things are all physical qualities. These are all things that are very hard to change, and the list goes on.

When you determine the physical qualities of a piece of land, you should accept those as they are, without the notion that you are going to change it. If you have a lot of rocks in your soil, you have the option of buying a rock picker. It is going to take a lot of time, a lot of money and many resources to get these rocks out of the field. In the end it is a lot cheaper to buy a piece of land that does not contain any rocks to begin with. If you already have a piece of land that you might have inherited, you come to realize there is a cost involved in making it suitable. If the slope exceeds, say, two percent you could bring a bulldozer in. You could level it. Again, there is a huge cost involved in it. I happened to be in a situation, about ten years ago, where someone came to me with just such question. It involved a corporation that wanted to have an organic farm as part of the business. They invited me to consult with them and said, "We want to grow vegetables here." My initial response was, "No, you're not. This land has too many obstacles." And they said, "Oh, yes, we are." I did not realize the amount of resources that this particular corporation had to make it work. And they made it work. So, it is not that it can't work, but nobody in here at least, has the resources to do it.

When it comes to the physical fertility of the piece of land, you can't make too many changes. I like to relate to the physical qualifications of a piece of land like the genetic code we inherit. Assume that you found a good piece of land. It is flat and has other positive qualities for growing vegetables; you still have to determine what kind of land it is. Is it a sand, silt, or loam soil? I tried to compare those soils to a riding or a work horse. The riding horse is going to be the sandy soil, you get there quick. It is a means of transportation. They provide you with early season vegetables. The workhorses are the silt loams. They give some real production all through the summer. It has a much larger window of getting through a drought.

So, in short, if you want to grow vegetables, try to get the best soils you can get your hands on in your particular area. In Massachusetts, the best is a Hadley silt loam; in Columbia County, it is an Unadilla or Occum silt loam. I have no idea what the good soils are in this area, but good land is the best place to start. We found a good piece of land.

Structural fertility

When you talk about structural fertility, you define how all of the different soil particles are connected and organized in relation to each other. When you want to evaluate the structure, you imagine a circle and draw a line through the middle; one half of it contains the pores in your soil filled with water and air with the other half containing the mineral component. That image is true for good vegetable land. It may not look like that for grasslands or for croplands, but especially when growing potatoes and onions you aim for a relatively fluffy soil. You can achieve that with equipment, but it is much better if you can accomplish that with other means. A good structure means it has a good ability for roots to penetrate, therefore a good ability to hold water and to drain water. Now again, all of this has already been said before today. I feel like much of what I prepared to say today is a repeat, and I will try to move into the more practical applications of everything we are doing at our farm. One thing that I might add and I haven't heard anyone mention today, is that when you have a clay soil, and I do not recommend this for vegetables, you can improve it by altering its chemical component to give it a better structure. When, for example, the clay contains low amounts of calcium, it will start losing its natural structure, it becomes unstable.

When we talk about tillage, I mean when you are working your soil, a rule of thumb is to take a lump of your soil in your hand and drop it down from four feet high. The natural breaking points of your soil allow this lump to be broken up in smaller pieces. This is a guideline how hard you should work your soil. Soil should have a composition that is build up of natural aggregates. Soil aggregates are relatively small, since you can hardly see them, but they make up the natural composition of your soil and are created by root activity, microorganism, and earth worm activity since they break up the soil, and through digestion glue soil particles of different sizes together. You can disturb this natural formed aggregate through the use of a tillage tool to create a seed bed when this is done in a violent manner. A rotovator is such a violent tool. What can happen is that these tiny aggregates, which we have seen some beautiful pictures of today, are falling apart. The consequence is that after a heavy rain storm the sand, the silt or the clay separate with the smallest particle floating to the surface, which causes crusting. This will have a detrimental effect on the quality of a seed bed. Root activity is a very important tool for soil improvement. I will talk more about that later. Biodynamic preparation 500 is another. Repeatedly, research shows that where the Biodynamic preparations have been used the soil shows increased microbial activity, and rooting depth of the plants. The homeopathic medicine that we use on our land has a real impact on its structural fertility.

Frost tillage is a common used tool in Holland in regard to light clay soils. I am not highly recommending the use of it in this country because of the timing of the plowing which has to happen in the Fall. Given our winters and slopes, exposed soil over the winter causes too much erosion. Harold showed a slide of how we were taught to plow back in Holland. The furrows were supposed to be nice and straight, and shiny. There was this whole idea about this shiny furrow that rested over the winter and after that it was beautifully broken up by the frost Only later did I learn that it was about the worst plowing job one can do. The Nordell's showed me the benefits of turning the soil only slightly without completely turning it over. When you make the choice to expose the ground and loosen it up before the winter it is amazing how that can change its structure. One trick that a lot of people may not know about is that you can cause the same effect over the summer. Over the summer when the soil has become extremely dried up, you can put your overhead irrigation on and drench the soil. This will fracture the soil as well.

This slide is an example of some good soil. This was a crop of rye being spaded in, and this is what you want to be looking for when it comes to a good structural fertility. The decision to take a field out of vegetable crop production is based on what I see. I do not have any tools available for me to know how the fungi actually hold the soil together, but you can see it. You can see in this slide that there have to be a good amount of mycorrhizae and other microorganism that hold the soil together. At the moment the soil becomes blocky and has straight edges, I know it needs a period of rest. I need to take it out of production. I have been working it too hard. Soil should never feel hard on your hands. It should be soft. It doesn't matter if it is clay soil or silt loam soil while it is very hard to create structure on a sandy soil. It is extremely difficult. It just doesn't have much to it. After incorporating a lot of organic matter on a gravely soil it will still feel hard. When it comes to the better quality soil, the silt loam and the clay, they can really feel soft to your hands.

Aeration incorporation, and seedbed preparation

Aeration is important both for the breakdown of the organic matter to release nitrogen, but also to create more pore space in your soil. Proper incorporation of organic material is a very important thing if this involves large amounts of organic matter. If you can't incorporate it properly, it can't properly break down. It has to be distributed into the soil. We need a quick breakdown in the process of creating a seed or plant bed. The moldboard plow has no use on our farm anymore – (showing a slide of land being plowed). This is an old slide, since it has been rusting away on our lot for it hasn't been used for a long time. The reason why, is when I noticed that the kale or corn stalks that were plowed under were still there buried in the ground at the end of the season. Nothing happened to them. You want to plow under, say, a tremendous crop of Sorghum Sudan or anything comparable. What are you doing? You might be creating silage down there. Is that the point? It really doesn't do a lot of good. The moldboard plow makes a beautiful seedbed though, because it doesn't take much but a pass of a disk and we are ready to seed. The plow makes the land look nice and clean. It buries all this organic matter.

After this, we went into a stage where we used the chisel plow. The chisel plow is a wonderful tool and we still use it a lot. It is a fast working tool. I like anything that can work up an acre of ground in 20 minutes or less. This width of the chisel shown here is about seven feet. The problem with this tool is that it leaves a lot of the plant matter relatively close to the surface (Harold would say this is a great thing), well, for vegetable growers it might be a problem if you don't have the right seeders. It will demand several next passes of discs and harrows to create the right conditions. I am trying to stay away from the disk completely because it has a tendency to cut the soil. It can cut the aggregates in pieces, while the s-tines have a tendency to find the natural breaking points. They rather hammer the soil all the time. This is the process of creating a seedbed.

The problem with this system is that you need to make many passes on your field, going back and forth, back and forth. First you go over it with a chisel plow, then with a disk, then with a Perfecta and then finally with something that makes a seed bed to make it nice and level. That is four passes. You have aerated the soil all right but you compacted it again by needing to create a seedbed. This felt very silly to me. So, a couple of years ago we purchased a spading machine, although I was forced to, out of the practical situation we found ourselves. The lease on our land had been terminated. I had to produce the following year and needed to find certifiable organic land. All the good land I found was in corn, and given the herbicides used, I could not grow vegetables on that land. The only land I found that would work was in sod. I had to get rid of a lot of sod and I wondered how I would get a quick break down. Moldboard plowing was one option. The chisel plow wasn't. I chose to spade the sod in the spring for vegetable crop production that year. It worked. It proved to result in a very quick breakdown of organic matter by distributing the organic material.

Here is an example (showing a slide of a spading machine), of what the soil looks like when you spade in sod. Extremely effective, mainly because of the secondary tillage action following the spades. This is not a machine that pushes the spades straight in the ground, which is preferable. This is a rotating spading plow. It moves very slowly. It is not at all like a rotovator. It picks up big clumps of soil with organic matter and it inverses it into the soil. You can set it anywhere between six and twelve inches deep. You can go relatively shallow with it. But the tool, the power harrow that goes behind will push all the bigger clumps deeper down. So, if you don't go over it again with a harrow and bring the clumps back up again, those clumps will stay deeper down and not interfere with seeding. If you wait long enough they will be decomposed by the time you seed. A problem when plant matter stays relatively close to the surface is that it will not decompose, since decomposition needs moisture.

(Showing a slide of incorporating full grown Sorghum Sudan) We also wanted to see how much we could do with it. This is a full grown crop of Sorghum Sudan. I wouldn't recommend it. It is just one of these things that we wanted to know what we could do with it. Under normal circumstances you would flail mow this Sorghum Sudan crop and then spade it in because, especially when the ground is a little on the wet side, it will wrap itself around the axle of the spading plow. It has also proven to be a good tool as far as looking at the whole farm system. We grow thirty acres of vegetables but can still look at it on a bed-by-bed case. As soon as the beds of squash are done harvesting we can spade it in and by the next day come in and plant a crop of lettuce. You can see here (showing a slide of a mulched crop of summer squash), with technology, this is what it was before – this is not a trick picture. We went over it exactly one pass.

Question: How many horsepower do you need to run the spader?

72 horse power for a two-meter spader. This is a heavy machine. The nice thing about the Italian models is

that you can do some real deep tillage with a much smaller model tractor. For example, comparable to a chisel plow in order to cover the width of your tractor you need a much more powerful with four-wheel drive compared to the same width with a spader.

Question: How is the rotating spading plow different from a rotovator? They look like they work the same.

Looks are very deceptive – I have to go back to the slide where you saw the rye. We dug the rye back up after it was spaded in. The integrity of the soil was still intact. When you talk about any particular fertility program on a farm it is really about preserving integrity. A rototiller or a disk invades integrity much stronger than this particular spading plow. All of the things that you see moving around move relatively slow. They take big chunks of dirt in the front and throw it backwards.

(Showing a slide of a bed former) We need to make one more pass to make a seed bed for carrots and salad mix with a bed former. We have a system where our tractor wheels are spaced at 72 inches apart, which allows for a 54 inch raised bed top in between the tires. This raised bed former was made in Ohio for tomatoes. They have a whole culture of plum tomatoes in Indiana and Ohio and they grow them on raised beds. It works very well for creating a fine seedbed. The tool is based on S-tines, staying away from disks as much as I can. S-tines will not pulverize my soil as much as the pan behind it will. It unfortunately kind of smears over the ground and every time you smear ground you are rubbing these aggregates apart. One thing you could do if you take the soil and rub it in between your hands you can see a discoloration there of the soil. That is how you can see where the particles are coming apart where the soil was one particular color before, you rub it between your fingers, and suddenly you can see all these other colors on your hand. That is because the sand, the silt, and the clay are becoming separated from the organic matter. This is what you do with tillage equipment.

Biological fertility

A lot has been said about this already today. I will go into the practical applications of it. I will let you read the handout at home when you have the energy.

The important part in fertility management for us is based on cows, or on other large hoofed animals. Maybe a little bit too much emphasis has been put by biodynamic agriculture on cows. They definitely have a role but other large hoofed animals can make similar contributions. I actually like sheep, especially integrated with vegetables. I like them a lot better than cows, since cows are incredibly heavy. I have tried it. I have had my cows graze some cover crops but I will never do it again. The ground is so soft in the vegetables they sink right in there. Sheep are much lighter.

The point of keeping large animals is that we need their manure and turn it into compost. I would never consider applying fresh manure. Manure is an unfinished product. It is half way there. It is great though. It is the first step in the process of decomposing plant matter. I feel that the cow adds a lot of qualities to the plant matter. The inside of the cow is like a plant within an animal. The inside of the stomach is filled with microorganisms that break down plant matter. When it comes out it is a very volatile product, because it is not completely finished or stable. You have to be very careful with it and if you do not treat it right you will lose many of its positive qualities.

In this particular case (showing a slide of a manure pile) you see that the material is being brought to a pile and then we mix it with horse bedding. Most of the cow manure that we are getting is on the wet side so we have to make it dry again with horse bedding. The particular person I am working with at Earth Works, Bob Walker, has all kinds of materials that he makes into compost. He uses cranberry pulp and any other organic material he can get his hands on. He needs to figure out the correct carbon nitrogen ratio when he has those materials in front of him. He looks at what he's got, determines what will make the correct C/N ratio, and then he mixes them all.

He uses a Sandburger turner (showing a slide of the Sandburger turner) from Austria and its inverts the pile. Whatever is on the outside goes to the inside, whatever is on the inside goes to the outside. After it has gone through the turner it has become a much more homogenous product than before. We add the biodynamic preparations to our piles. The way you can look at a compost pile is to think of having another animal on the farm. It is not a true analogy or true metaphor but just an attitude type of thing. It is like an animal since it has all the qualities of an animal like body warmth, moisture, organs (by adding the biodynamic preparations), and a skin (by covering it with the covers). I obviously actually take this very literally, but I do not ask you to do that. The Valerian preparation should function as the skin. We find that it is not sufficient enough especially in our climate where thundershowers can bring down two inches in one hour. The skin we are providing is a cover made out of a polyester type product that sheds the rain (while still allowing it to breathe).

Rain can be a tremendous enemy of a compost pile. Once water saturates the pile it will stop the composting process. On the other hand, it also prevents it from drying out too much. You can imagine all that heat, you can see here it is about 150 degrees, will dry the pile out quite a bit. We use the same turner either to cool it down or when it is too dry to insert water. We can spray water into the pile. Other places where the analogy between a compost pile and an animal hold up is the following. When you have a cow, you check on it every day, right? Well it is somewhat similar with a compost pile. You kind of look at it, you follow it. You don't have to feed it that is the nice thing about it. But, you do have to give it water and you have to monitor what the condition is. If you are going to do a good job, it will be free of pathogens, it will be free of weed seeds, and ultimately if you do a good job, it will have disease suppressant qualities.

(Showing a slide of a table of organic residue per crop) A most important contribution of compost is in raising organic matter effectively in comparison to cover crops. In your handout, I added the information of what ten tons of compost adds in organic matter, which is not on this slide here. It is very interesting when it comes to numbers. When you apply ten tons of compost each year in comparison to what these different crops are doing, you can see the winners of all crops are three years of a grass clover mix. But all of this organic matter is relatively fresh organic matter at plow down. Ten tons of compost results in about six and one-half thousand pounds of organic matter per acre. This is a substantial number, especially taken into consideration that after one year most of this is still going to be there. Even after growing three years of a grass clover mix; only a third of the organic matter is left after one year of breakdown. Most of it gets broken down.

Also, this table shows that growing vegetables is detrimental in maintaining organic mater levels. At least two or three percent of the organic matter is being burned up all the time through cultivation. Not only the nitrogen but also the organic matter is being mineralized. So, if you grow onions year after year you could see that you are in a rapid declining state here. Maintaining organic matter is done somewhat if you put a field for one year in clover. It is much better than doing nothing, but all you replace is about a thousand pounds of organic matter. How much is that really? That thousand pounds of organic matter is approximately 1-2% of the total organic matter reserve in your soil.

(Showing a slide with a table showing increase of organic matter by sod and rapid decline following by crop land) Most of these tables are based on the Bemesting en Meststoffen textbook. It is translated in the table in your handout. It shows total organic matter. I find this a fascinating table because you can see how long it takes to build organic matter. Now look at that number 50. That is tons per acre. A little different numbers than what John showed us. I think John showed us a table that was based on 6 inches. This one is based on 12 inches of topsoil and in 12 inches of topsoil, there is I think 2000 tons of soil or was it 4000 tons. But anyway, 50 stand for about 2.5% organic matter if you want to convert it. So, we start at 2.5% and we are going to go up to approximately 3.2%. Over a period of 25 years, this is if you have it in continuous sod. So, we are talking about going from 2.5% to 3.2% by having it in continuous sod. The formation of the prairies, you can now imagine how long that took. It is a slow process. So here, we are considering growing cover crops to raise organic matter. That is a great consideration, but what we really need is 25 years of sod. And once we go back to cropland we are back to where we started in 10 years. So to maintain organic mater levels, and I do not know if I go out on a limb here, does that mean then, that out of every one year of cropland you have to balance this with 2.5 years of sod? Well that is where I think the compost has its place. The compost will effectively maintain the organic matter. I caution you though that too much compost can have negative effects as well, (like raising phosphorus to levels that it will pollute the ground water).

(Showing slides of a crop rotation) What I want to do next is to go into some crop rotations. My crop rotations have many cover crops in them and you might ask why I bother. I just showed you that cover crops don't increase organic mater levels. Well it is not so much the objective of raising organic matter when growing cover crops. The reason is more in supporting structural fertility. I have not seen any evidence by spreading compost, that I am supporting the soil structure. I have not seen the relationship between adding a lot of organic matter and increasing the soil structure per-sé. Especially not if I raise vegetables in a very intense way accompanied by an intense regime of tillage. I have grown two crops, sometimes three crops a year, which requires a lot of tillage. We used tremendous amounts of compost because at that point Earthworks was still in its early stages, heavily supported by grants and the best place to put it was on our fields. So, we were raising our organic matter in six years from 2.5 to 3.7. It was great. But was there really an increase in structural fertility? Not as much as I hoped for.

What I also saw was a weed cycle where we initially encountered a lot of pigweed and lambsquarters, chickweed, galinsoga, and purslane came in. Tomorrow there will be a lot more about weeds, and weed control, but let me say a few things about this in relation to rotations and cover crops. When you leave the soil exposed and you work it too hard by breaking down its structural fertility, I believe, and this might be too flowery for you guys, that the soil is self corrective by wanting to cover itself up again. So, it is looking for the crop that will do this the quickest and most effective way. Well, chickweed and purslane are perfect in doing just that. The wisdom in the soil is looking for ways to cover up the mistakes that we make. As a result the crop rotation I will show you has incorporated grasses and legumes. Grasses and legumes are other crops that are very effective in covering the soil. They are able to, as was said before by Harold about nudity, put some clothes on that soil in a very effective way.

The other component about the following crop rotation is that it allows doing some very aggressive weed control by introducing the bare fallow, which is possibly detrimental for some of the microorganisms and soil structure. The crop rotation serves the two purposes; increase structural fertility and providing control for diseases and weeds.

I just want to walk through some of these rotations with you. Here is one where we start the very first year with oats and sweet clover. The reason why I use oats as a nurse crop is because the sweet clover germinates relatively slow and the oats is a good way to immediately help the soil, to anchor it so to speak. Later on after the oats is mowed down, the sweet clover will fill out.

The following year we spaded the sweet clover in to provide a wonderful nitrogen supply for my sweet corn. We over seed the sweet corn with red clover, with the following year the red clover being followed by a bare fallow. I incorporate the clover sometime in the summer when the ammonia, there is a tremendous amount of ammonia becoming available out of the red clover, is then easily being taken up by the soil and being converted to nitrates. That freely available nitrate then has to be anchored again by the oats and peas that are followed by potatoes. It is a challenge to get enough of nitrogen to my potatoes, while getting potassium is usually not a problem. It is available in the compost or I can spread Sul-Po-Mag (an OMRI approved potassium fertilizer). But getting enough nitrogen is difficult for both growing potatoes or corn and it needs clover incorporated in the rotation.

The potatoes are followed with an oats and peas crop. The potato crop serves almost as a bare fallow. There are hardly any weeds in the potatoes, first because a bare fallow preceded it, but also because the potato is very easy to cultivate since you keep hilling them. The oats and peas are chosen as winter cover crop because winter kills both, since we don't want to do a lot of tillage, especially deep tillage, in the spring. When you do deep tillage you are going to bring more weed seeds up again, this is not a good idea, especially not after a bare fallow.

So, here we follow the oats and peas with onions. The onions come out of the ground sometime around the middle of August and are followed in September by rye and hairy vetch. The rye and hairy vetch are mowed down a few times and then incorporated to be followed by fall broccoli, or we (mow it once and) harvest the rye for straw. After the fall broccoli there is no cover crop. There is nothing to protect the ground over the winter and the ground is open. The good thing is that there is very little plant debris and we can follow with a fine seeded crop like early greens or spinach or lettuces. It can be anything as long as it is not a Brassica itself. Any rotation keeps families following each other with the exception of the legumes and grains.

Now lets move ahead for a moment. We are going to show a few pictures.

Q: When do you apply compost?

A: Every time before a cash crop, ten tons of compost is applied in the spring. Right now we apply ten tons. I think that at a certain point, you should be able to bring that number down, but I agree with Brian that in the earlier years you really need to apply at least ten tons per acre. It is a lot of money, so you have to ask yourself if you can afford that. Another option would be to spread smaller amounts of compost, and supplement what you can't get out of the compost from other sources, either through side dressing or any other way.

Q: How do you incorporate your cover crops?

A: We use a spading plow followed after flail mowing. The spading plow is the primary choice for incorporation of large amounts of organic matter.

(Showing a slide of mature oats) Here the oats were not cut down and I will never do it again, I'll show you why. This was a very dry year and the oats very much competed with the sweet clover it was a very poor stand so we are not taking that risk anymore. This was also kind of a dry soil to begin with, but you can see what a poor stand of sweet clover we have there (showing a slide of very small plants of sweet clover under a crop of oats). It was right before we combined it. At that point, I was greedy, I wanted to get the oats, and I wanted to get the grain. Right now, not having our cows anymore, there is no need for that. So, we mow the oats probably twice and then we mow it a third time (the clover).

This brings up another important thing; mowing your cover crops. Ted Blomgren did an interesting study using an infiltrometer. I don't know what it looks like but I understand the concept. It measures how much water the soil is able to take in. There were three plots – one plot with three years of cover crops, one with one year of cover crops and one year that was in vegetables. Guess which had the highest infiltration – it was the vegetable land. That wasn't what I expected. Weren't cover crops supposed to create those nice pores and structural fertility and everything else because that is the idea? The more air, the more pores you have the quicker the water will actually infiltrate. We heard some remarkable numbers from Mary-Howell and Klaas Martens about their land. He was very much surprised. What I wonder about is that he was dealing with vegetable growers. Those people probably went out and cut their cover crops when they ran out of work everywhere else. Well, when do you think that happens? After it has rained a couple of inches. The priority was to get your cash crops in. When they ran out of all that work, they mowed down their cover crops and compacted their soil. So, it wasn't a surprise at all, that the land that had been in cover crops for three years was extremely compacted. You have to look at your soil improvement crops as you treat your vegetable crops. Be careful using heavy tractors when mowing them down. You are driving a lot on there. We are mowing up to three times a year, which greatly helps in controlling weed populations, but you have to be careful. Those are heavy tractors, 7,000 pounds or more. I don't know how many pounds per square inch are underneath the tractor tires, but it does add up.

(Showing a slide of red clover) This is actually not sweet clover it is red clover – we'll come to it later in another rotation. This slide is taken around mid-summer. You see we are treating the field in one piece. Now we are dividing the field in sections. The whole farm is divided up into sections with a varying length but eight beds wide. Each section is divided and separated by a harvest lane. The eight beds in these sections, come close to being permanent. The tire tracks will fall in the same place, year after year, after year. The grass and clover strips in between are also permanent. It also allows for very good record keeping as far as rotation is concerned. The 70 acres that we operate, 30 acres at one time are in cash crops and the other 40 acres are in soil improvement crops. The way that we keep track of it is section by section. Here you can see that where one section is prepared for seeding. We spaded in the clover and then seeded down with oats and peas. That will be the following year in potatoes.

Here is the last cultivation of the sweet corn (showing a slide of young corn plants). After the last cultivation of the sweet corn, the red clover is over seeded. We do not wait a day, we have someone cultivating and hilling up the corn with another person walking behind with a cyclone seeder. It is one of those things you get at Johnny's Selected Seeds. It looks somewhat silly but it goes pretty fast. We are seeding our clover down at a rate of approximately 20 pounds to the acre. This is red clover. I tried sweet clover. It doesn't handle the shade very well and it doesn't handle the traffic very well either. (Showing a close up shot of sweet corn) You can see these are not weeds. The ground is clean at this point and you can see that the clover has germinated. You can see this is after harvest (showing corn stalks with a green cover on the ground). The corn has been harvested. The clover has established itself successfully. We then mow the corn down (showing the sweet corn mowed down)– you can see the stubbles there. It pretty much fills out. The rest of the rotation follows.

Pretty much this rotation is based on a system that was described earlier. Oats and barley over seeded with legumes is a very common practice at biodynamic or organic farms in Europe. I wondered how we could do this with vegetables. The last example I show you is one where we seed red clover at the beginning of the rotation – by the way if it is a seven-year rotation –At the end it will start the following year back at year one again. When you start red clover, you do not need a nurse crop like with sweet clover.

(Showing a slide of a tractor pulling a grain drill in a large field) Just as a note: we operate those 70 acres of land with 30 acres of in cash crops by myself, my partner Jody Bolluyt, four apprentices and two seasonal workers. That is close to 10 acres per person and we really don't work hard. We like to work 40-45 hours a week. It is a matter of approach. A lot has to do with the fact that we put systems in place. The down side is that it takes a lot of land. But we have been able to cut down on the number of hours per cash crop per acre. We spend most of our time harvesting, which is key. We spend very little time on insect or pest or weed control. Weed control is something that takes five to ten hours a week for one person, besides the finely seeded crops that are being weeded by hand. Otherwise, we never touch potatoes, corn, cabbage, etc. by hand. It has to be a weedy piece of ground for us to hoe cabbage.

Another word on rye (showing a picture of rye and vetch in bloom). We grow quite a bit of rye and hairy vetch. If we want to harvest the rye, we do not mix in the hairy vetch. It really becomes a mess (trying to cut it). Has anyone tried to cut rye and hairy vetch with a haybine before? I destroyed a haybine with it. It was an old haybine, I admit. But hairy vetch just clogs up the mower, which can be really awful. If you want to make your own rye straw, a sickle bar mower would be the best thing to use. We use a lot of rye straw as mulch.

This is garlic (showing a picture of a mulched field). We used a lot of mulch in between the black plastic. I will really shoot through these ones (slides) very fast because they are outdated. The reason why they are outdated is that our workers refused to work with straw. The allergies that people develop these days are inhibiting us from using large amounts of rye straw, so we still use it in our strawberries and garlic, but I had to find another solution for what to use in between the black plastic.

The solution that we came up with is living mulch. This is annual rye grass in between tomatoes (showing a slide of staked tomatoes with a living mulch). The three acres that we have in drip and black plastic is seeded down with Dutch white clover. This is one of those examples of a successful combination of a cash and cover crop in the same year. To establish the living mulch, you want to make sure you lay all of your plastic as early as you can to seed your Dutch white clover. Don't wait as you may usually do and lay your plastic as you need it because if you wait until May and you seed your Dutch white clover the weeds will get ahead of you. I had a very interesting situation and if I had a couple more hours to talk I would talk about that more, but when we got the new farm we ended up with three different pieces of land. One was in rotation of potatoes and corn, the other one was continuous corn and the other one had been in a corn/alfalfa rotation, with four years alfalfa, and four years in corn. The one that was in corn and potatoes was heavily infested with purslane. I really did not know what to do with it. I seeded some Dutch white clover to see what would happen and to my great surprise it suppressed the purslane. When we laid black plastic in that field the Dutch white clover suppressed the purslane the whole season. It provided a beautiful cover. A note of caution is to make sure you use Dutch white clover. We once seeded from a bag that said white clover on it. It was not white but red clover (which is an aggressive grower), it actually grows right over the plastic, and it starts invading your cash crop. Not a good idea. It has to be Dutch white clover, not because it is Dutch, just because it is small.

Over seeding of red clover in winter squash (showing a slide of winter squash getting hoed) should be done at the last cultivation. Some people asked me earlier if you don't have to rake the clover in. Again, I don't think I have stressed enough you don't have to as long as one person is following the cultivating tractor. The seeding happens within moments after the last cultivation. The ground is nice and soft and it falls right in between those cracks. It germinates quite well. But if you wait, especially if you wait after a rainstorm to seed your white clover, it is not going to work very well. You are going to have to roll it in, rake it in, or do something. The incorporation of the clover seed happens by the ground being recently worked. This is actually a member's workday here. We have members come up once a month helping us with hoeing and harvesting. We have 700 shareholders that support our farm.

Here you can see after the harvest (showing a slide of clover). You can see it is completely filled out. This is actually another slide right after harvest. Here you can see there are some patches that where underneath the plants that surprisingly well filled out. That was the last slide.

Questions

Q: When you over seed the clover to the previous crop do you find any disease problems with keeping that crop on the ground through the fall/next year?

A: In the case of winter squash there were a couple of reasons why I over seeded. Since we don't like hand hoeing or hand weeding, winter squash is one of those crops where we always saw a few weeds going to seed. We have members hoeing there, and that is great because they can get those weeds that the cultivator did not get. Normally speaking we would not have time for it and a few weeds would go to seed. The advantage of over seeding instead of disking in your winter squash crop residue, which some people said they do to prevent diseases in future years is the following. First, in this crop rotation the cucurbits do not come back there for another five, six, or maybe even seven years so disease is not a problem. The problem with the winter squash is when we work in our weed seeds to establish a cover crop. These weed seeds that are buried can be a problem in future years. With over seeding the weed seeds, like lambsquarters or anything else that goes to seed, dies down, and we'll mow it. The weed seeds lie on top. The birds will get it, smaller insects will get it, or it germinates the following year underneath the clover. It actually gives many advantages and does not create a lot of problems.

There are some problems though with having too many cover crops. There are some problems associated with cover crops as well. We have all this raw organic matter, which provides this incredibly nice environment for some of the insects that we don't like to see. We have problems with thrips because they come flying out of our grains after we cut them down and infest our onions. We really need to think about that. It might mean that we should always leave some grain standing up for them to go to instead of flying into the onions.

Q: Are the cover crops hosts for leafhoppers?

A: I find it mostly with alfalfa. I have not seen it with the clover. If clover is the host of that as well, we haven't seen it, yet.

Q: Do you mow the clover?

A: The living mulch we do not mow, but if you have red clover, you do have to mow it. Again, we had red clover because of a mistake we made and we mowed it three or four times. We did not have a problem with tarnished plant bug; we had a problem with leafhoppers. Again, I am assuming that they came out of the cover crops and came flying right in. I would say our biggest problems with insects right now are flea beetles, cucumber beetles, thrips and leafhoppers. Colorado potato bugs are almost nonexistent. Why? I have no idea. I assume that some crops are serving as a host of their predator either over the winter or at other times.

Q: (Most of the question was inaudible) Something about nitrogen in compost, when do you cut back, will cover crops be enough? What are you thinking about in the long term?

A: Long term is to involve animals and then a lot of the fertility (from the soil improvement crops) will be exported from the fields in the form of feed. It means instead of cutting them down and plowing them in, you bring them to the barn and feed them to the animals over the winter. Bringing the composted manure back will mean we will import less compost from the outside. In other words, it will be a cycle within the farm.

Q: Will you cut back on the compost?

A: I think compost is very important. I don't think a system within vegetables would ever work on cover crops alone. I think you eventually will lose important nutrients that are needed. I think the animals play an important role within the farm, and they will allow you to import less compost. Maybe that is something that you want to aim for at one point, which is to import less compost. Lawrence B. Hill said, "Plowing under a cover crop is like a crocodile in a fish pond" – it is a lot of activity and then it is very quiet again. Soil life becomes very active and John said it earlier it is almost like applying liquid fertilizer. So, cover crops have their place for root formation, but maybe within the farm system as a whole system, there is more wisdom in feeding it to animals. Removing a lot of the above ground plant matter, feeding it to the cows, building a compost pile and then bringing that back in the form of compost seems to be a lot more sensible, while there is still a lot of that structural fertility being built by the plant roots. That would be the long-term picture.

Fertility Management at Roxbury Farm

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To evaluate the fertility level of our soils, there are four different characteristics to distinguish.

1. Chemical fertility

a. Hayfields

Hayfields are generally self sufficient in nitrogen provided there are plenty of legumes part of the hay mix. You might see your neighbors using generous amounts of nitrogen fertilizers on their hayfields, and in Holland, they practice this as an indirect weed-killer. The only plants that do well with an oversupply of nitrogen are the grasses. Grasses have a great ability to choke other plants given they are supplied with lots of water and nitrogen. High nitrogen levels also reduce the uptake of nitrogen by rhizomes that live in symbiosis with the legumes.

The best improvement in a hayfield is it to make it part of a rotational grazing system, in which cows are allowed for very short periods (1 to 3 days) to graze. In alternate years, the field is hayed with still allows for a fall grazing period. The most productive hayfields are usually the ones with the greatest number of species, considering the time an alfalfa field is out of production for reseeding purposes.

The annual potash requirement for the hayfields averages around 80-110 lbs./acre. Roots and microorganism can extract some potash out of the rock content of the soil or draw some it from the subsoil, provided the soil has no hardpan. An annual gift of 14 tons of cow manure provides 110 lbs. in potash.

The annual need for phosphate is around 25 lbs./acre. Three tons of manure would cover that need (based on average manure samples). Most manure contains relative high amounts of phosphate caused by the grains fed to the animals.

b. Vegetables

All vegetables have different nutritional requirements. A rule of thumb is that:

- Most vegetables have relatively low needs for phosphorus.
- Leafy greens have higher than average needs for potassium.
- Most recent developed vegetable varieties do well with high levels of nitrogen.
- Most vegetables need a pH between six and seven.

Compost or manure releases only about 40% of its ni-

Table 1
Average Nutrient Absorption For Vegetables

Vegetable	Nutrients in lbs./acre Nitrogen	Phosphate	Potash
Asparagus	11	3	6
Beans green	120	10	55
plants	50	6	45
Beets	140	14	140
Broccoli at 10,000 lbs. heads/acre	20	2	48
plants	145	8	160
Brussels Sprouts	140	20	125
plants	96	9	110
Carrots at 30,000 lbs. roots/acre	80	20	200
leaves	65	5	145
Cantaloupe at 22,500 lbs./acre	95	19	120
Vines	63	8	35
Celery at 100,000 lbs./acre	170	35	387
Roots	25	15	55
Lettuce at 35,000 lbs./acre	95	12	170
Pepper at 22,500 lbs./acre	45	6	50
Plants	95	6	90
Spinach at 20,000 lbs./acre	100	12	100
Sweet corn at 13,000 lbs./acre	55	8	30
Plants	100	12	75
Potato at 40,000 lbs./acre	150	19	200
Vines	60	11	75
Tomato at 60,000 lbs./acre	100	10	180
Vines	80	11	100

Adapted from Knott's Handbook for vegetable growers

Average uptake from vegetables is:
- 81 lbs./acre nitrogen (available in ±8 tons of compost)
- 31 lbs./acre phosphate (available in ±4 tons of compost)
- 122 lbs./acre potash (available in ±10 tons of compost)

trogen the first year with the remainder released in the following two to three years. When we spread the manure in the fall, losses of soluble nitrogen are high and we can only utilize 20% in the following year.

Nitrogen from cover crops, when plowed under, is released over a very short amount of time and care should be taken to avoid losses. Most of the nitrogen from cover crops consists of ammonia (highly volatile). The nitrogen in manure consists for about half of ammonia and with the other half in nitrate, and in good compost, all ammonia is converted in nitrate.

A soil test will give some indication of where the state of your soil is. But besides giving accurate numbers for its pH and OM, It rarely allows for a good prediction of what the yields will be in an organic system. I have seen many instances where good soil health (good

Table 2
Different Compositions of Several Organic Fertilizers

All quantities in lbs./ton, except the first column

Type of fertilizer	Per animal in lbs./180 days	Dry Matter	Org. Matter	N	P	K	Ca
Roxbury Farm Compost		924	327	12.5	8.25	12.6	20.3
Cow-dairy							
Solid	13,000	430	280	11	7.6	8	8
Urine	9,000	52	20	8	.4	16	.2
Slurry	22,000	190	120	9	4	10	4
Pig							
Solid	770	460	320	15	18	7	1.8
Urine	990	40	10	13	1.8	9	1.2
Slurry	1,760	160	126	14	9	8	1.5
Chicken							
Solid	44	640	460	25	37	18	47
Slurry	88	220	160	16	13	10	22
With bedding, (Free range)		1,160	700	32	40	22	57
Horse		620	500	10	6	11	6

Adapted from: Bemesting en Meststoffen by W.T. Rinsema PhD

structure, good biological diversity, and good physical qualities override its chemical contents.

The reality is that hay would do very well with an annual gift of 2 to 3 tons of cow manure to the acre, while vegetables need more than what the numbers from a chemical analysis suggest in order to produce a competitive yield. Vegetables do not support structural and biological fertility and their roots rarely extract minerals from the rock content of the soil.

2. Physical fertility

There are about 250 acres under Roxbury's management.

What crop is growing on it is a direct result of the soil type we are working with. The presence of large rocks, steep slopes, or poor drainage makes some of this land unsuitable for vegetable crop production.

Good vegetable land has:

- A high carrying capacity (carry the weight of equipment without creating irreversible compaction)
- Good drainage
- Good access to irrigation water
- A deep A horizon (topsoil) that is free from stones
- Is almost flat with slopes that do not exceed 2%.

- Is located in a long season micro climate
- Good exposure to sunlight
- Good air drainage to avoid late frosts.
- Good access to farm roads

At Roxbury Farm the 100 Acres that are suitable for vegetable crop production, only 30 are planted in cash crops each consecutive year. 40 acres are planted in soil improvement crops with the remaining 30 rented out to a neighbor for hay. Almost all of the vegetable land is rated category I or II (Occum, Unadilla, Knickerbocker, and Hoosick). The remainder of the land is rated lower and divided between hayfields, pastures, woods, or wetlands. They are still important in providing a broad biodiversity to the whole farm.

When we assess the physical quality of our soils, we determine its physical strength and limitations. Working with land is not unlike working with a horse. First, we need to know what horse we are dealing with. Is it a workhorse or a riding horse? Each has different qualities. We will not try to pull a heavy load with a riding horse. Within this analogy, a sandy soil has qualities of a riding horse. Although it has its usefulness, we cannot get a lot of work out of it. It might pull a plow but it lacks the persistence of a workhorse to complete the task. Sandy soils, are great in the early spring since we have early access, since they drain well and warm up. But in the summer, they easily dry out, and can only achieve good yields with solid set drip irrigation. A workhorse on the other hand keeps moving, albeit at an initially slower pace, but with much greater resilience. A heavier soil, like a silt loam resembles a workhorse. They are a little later to warm up in the spring but their ability to hold nutrients and water gives them a great advantage over the summer months.

Nutrition is another analogy between horses and soils. Despite Too much compost to alter its physical characteristics, which results in excessive amounts of soluble minerals, creates high disease and weed pressure.

Starting off with a good soil is the best investment a vegetable grower can make. Altering the state of its soil is hardly ever cost effective.

3. Structural fertility

The way soil-particles are connected and organized in relation to each other reflects on its structural fertility. We evaluate how the soil particles are spaced and how many and how large the spaces are in between them. By the use of tillage tools and the compaction of tractors, the soil aggregates are broken. When the soil is worked too hard, it will not stand up to a heavy rainstorm and will collapse and erode. Soils with stable aggregates are more stable. Some soils do not have the physical characteristics to create stable aggregates. In that case, the only remedy is adding organic matter.

A stable structure will have:

- An equal distribution between mineral particles and pores.
- Good ability for roots to penetrate.
- Good ability to hold water.
- Good ability to drain excessive water.

Hay fields and pastures are in general self sufficient in creating good soil structure. Their root system supports many microorganisms that feed directly on plant matter or live off the conditions created by the roots during growth as well as decay. In general, most grasses create a surplus of carbonaceous materials, and the organic matter content of the soil increases. This will help connect the soil particles into stable aggregates. Microorganisms feed on the decaying organic matter and together with the extensive root system of the grasses help the way in which the soil particles are ordered. They leave many pores, which will provide drainage and capillary action in times of drought. Vegetable crop production, by its nature of exposing the soil and introducing equipment, do not maintain soil structure. Besides this, most vegetable crops do not have very well developed root systems unlike most grasses.

Strategies to support good structure are:

- Supply high amounts of organic matter that contain humus formative particles.

- Add Calcium as building block for clay soils.
- Avoid breaking up the soil beyond natural breaking points
- Increased root activity by using soil improvement crops.
- Increased root activity by using Biodynamic preparation 500.
- Frost as an action to fracture compacted soil.

To help determine how we treat the soil during the season tillage tool should not fracture the soil more than when we drop a clump of soil from a height of three feet. Ideal is to use tillage equipment that has an action similar to that of a hand-fork. A hand fork fractures the soil at its own breaking points. A spade and damages the aggregates where it slices the soil. The coloration at the back of the spade is an indication of smeared soil particles. The aggregates that order the soil have come apart.

Three different purposes of tillage:

- Aeration of the soil. (Depth anywhere between 8 and 18 inches)
- Incorporation of organic material. (How deep do you want to put your organic material?)
- Creating a seed or plant-bed. (How smooth and level does this have to be?)

Conventional equipment rarely combines all three tasks. Only a spading plow with secondary attachment will accomplish this and it will aerate at the same depth as it puts the organic materials.

For primary tillage, a Chisel plow is used to aerate the soil. In order to incorporate cover crops with this tool the use of a shredder or flail-mower is necessary. The chisel plow does not turn the soil and leaves a lot of plant matter on the surface. After the primary tillage, a Perfecta II Cultivator is used to smooth out the field. This tool consists of a combination of several "S" tines, a leveling bar, and a set of crumbling rollers. It leaves the soil level and smooth enough to plant: cover crops, Cole crops, potatoes, squash, and even lettuce-plugs. For crops that have small seeds and that require extremely level ground with no clumps or stones on the surface a Buckeye bed former is used. This tool leaves a trench every 72 inches, creating a soil surface that resembles raised beds. The planting surface of the bed is 54 inches wide and allows for three rows 18 inches apart. The trenches have proven to be very successful in allowing the crops to stay dry much longer during periods of heavy rain. The combination of better drainage and the level plant bed prevents bottom rot and creates conditions for successful mechanical weed control.

4. Biological fertility

Here we recognize three areas of importance:

- The cycles in nature, that includes decay and decomposition of organic matter.
- The creation and maintenance of soils.
- The nutritional value of cultivated plants.

At Roxbury Farm this is addressed with the following measures.

A. Applying compost and incorporating soil improvement crops increases soil fertility

Fresh organic matter, is important to add to the soil because:

- It feeds the microorganism.
- It keeps the nutrients in a cycle.
- It creates a better structure of the soil by acting like glue to the soil particles (Fungi).

Ultimately a good soil transforms this organic matter into...

Humus

Humus, the most stable form of organic matter that:

- Has the ability to absorb both nutrients and water. Humus compared to clay can hold up to four times as much water, and the nutrients in humus are available to plants but cannot be washed out by excessive rainfall.

- It increases the structure of the soil.

Compost

Roxbury Farm works closely with the company Earthworks. This company was formed with the help of the state of New York to research the possibility of keeping organic materials out of the landfill. Earthworks collects produce from supermarkets, horse bedding from farms, and pulp from canneries. These materials are mixed with a Sandburger compost turner and carefully monitored for temperature and moisture. This machine is also utilized to make compost from cow manure to be used at Roxbury Farm.

The process of making compost at a biodynamic farm

During the winter, the cows are usually kept in a free stall setup. In this method, the hay is fed in the form of round bales inside the stall and placed on top of the packed manure. The cows are kept off the manure by applying bedding on a regular basis. This can consist of old hay, straw, and or wood chips. If an adequate source is available, rock dust, like Basalt meal can be added to the manure pack. After six months, the packed materials are about three feet deep. In May, the manure is removed with a bucket loader. The pile is build with a manure spreader, with its final shape created by the turner. The biodynamic preparations are inserted into the pile by pushing a long stick two feet into the pile. Only small amounts are needed in each hole to prepare a pile.

A variety of materials in a manure-pile allows it to be mostly self-sufficient in the process of transformation. A pile that has a variety of materials in it develops a combination of aerobic and semi-anaerobic bacteria. The piles heat up 120° to 160° Fahrenheit and stay at that point for quite a few weeks. A specially designed cover is placed over the piles to shed of any excessive rain and to keep the moisture in. The cover functions like a skin. It protects the pile from the elements without restricting it from breathing. A pile behaves like any other organism on the farm: it breathes, consists mostly of water, and has body warmth, except it will not break any fences. The piles are turned when necessary, and water can be added. The whole process of composting takes about 6 to 12 weeks. The compost, when applied is not finished, but will have lost most of its odor. The ideal time of application is on a cloudy day with plenty of rain in the forecast. After application, the ground is chiseled or spaded. Manure handling can be the weakest link in the farm's fertility cycle. At a biodynamic farm, it is important to keep nutrient losses as low as possible.

Fibers play an important role in the composting process. Most fibers are "used up" at the end of the composting process. Hay and straw are good examples of being good energy providers for the microorganism. Their presence is vital in the process, but it is important to include materials that contain lignin. They take a longer time to break down, and this kind of carbon compound is not readily available as an energy source for the microorganism. But at the end of the composting process, they contribute to the formation of humus at a much higher rate than fibers do. All carbonaceous materials have a different ability to become humus. The materials with high lignin fractions, like peat moss, sawdust, and leaves have what we call a high humification coefficient. They alone cannot provide the microorganism with enough energy to start the decomposition and hay, straw, or green material has to be added to the pile to jump-start the process. The manure contributes nitrogen and other building blocks that are used by the microorganism to grow and multiply. By adding soil or rock dust to the manure, we create conditions that can occur only under ideal circumstances in very good soil. The humus can transform into a clay-humus complex. This aggregate represents the most stable soil component, which has a very high capacity to hold nutrients and water.

The eventual goal in applying good compost to the land is to increase the overall health of the soil. Compost is also very effective in raising the Organic Matter level of our soils

B. Soil improvement and cover crops

The benefits of cover crops and soil improvement crops

Reduction of soil erosion. A crop of rye seeded in September and plowed under in April is able to keep the soil from eroding away over the winter months. Rye and hairy vetch as a mix are very effective. And will add to soil-life, though the humification coefficient can be very low, soil life is greatly benefited by the mere fact that the ground is not left exposed. The roots of the cover crops after breakdown form the very important capillaries for drainage as well as water uptake.

Increase of pores in soils and breaking up hard pans. Sweet clover is known for its deep penetration of the soil and breaking of hard pans. But any established grass will greatly increase the amount of pores in the soil.

Increase in microbial activity. Soil particles are held together by microbial activity especially the group of fungi. Without activity of roots providing microorganism the needed air, and carbon for their activity very little microbial action would exist.

Increase in organic matter content through carbon intake. Grasses are known for their excellent ability to fix carbon out of the air. For greatest uptake of carbon in one season, Japanese millet and sorghum-Sudan are favorites.

Fixation of Nitrogen through rhizomes living in symbiosis with legumes.

Weed management. Many crops are able to choke out other weeds, and by frequently mowing of our cover crops, we reduce the number of weeds going to seed.

Plant disease management. Most cover crops do not host plant diseases known in cash crops

Overall farm diversity. Most insects feed off the pollen of the grains and grasses. In some instances, the cash crop acts as a beneficial host. The pollen of the sweet corn is a good example. For that reason, parsnips can be left in the ground to flower in the spring. The flowers that are formed in the following spring provide a habitat for the trichogramma wasp. Dill, which is another Umbelliferea, serves the same function. After the dill is cut, the plants remain alive and produce flowers at a time when the parsnips have gone to seed.

The roots of the legumes live in symbiosis with microorganism called rhizomes. Look at the roots of the legume to find out if nitrogen is in the process of being fixed: if the roots have nodules that are red or pink colored inside, it has active rhizomes. If the roots do not show nodules, find out if the soil pH is too low or if the particular rhizome is in your soil. Many legumes live in symbiosis with different rhizomes.

Disadvantages of cover crops

Sod can provide a cover for the eggs of many insects. Flea beetle and carrot-fly take advantage of this environment. Grains and Alfalfa hosts thrips and leafhoppers. Once the grain is combined or the alfalfa cut, the many insects including thrips and leafhoppers look for a new home. As we increased our acreage in grains and legumes so have our problems with thrips and leafhoppers increased. One solution is to have another crop available (besides the vegetables) for the insects to migrate to and to never mow all the cover crops at once.

Another detriment from too much raw organic material is the residual activity in the soil that can manifest itself like fresh manure. Many diseases and pests like aphids' increase when too much raw fertility is applied. Lawrence D. Hills of the Henry Doubleday Soil Association, once said: "Plowing under cover crops is not unlike throwing a few fish in a pond filled with crocodiles." Crocodiles are a beautiful metaphor of soil life.

What we seed in different months in New York

April and May

- Oats with red or sweet Clover
- Rye with Dutch white clover on head lands (the Rye will not form a seed head)
- Dutch white clover in between plastic

May and June

- Buckwheat after spinach or other early crop
- Sweet clover, red clover over seeded in the sweet corn and Winter squash.

July

- Japanese Millet or Sorghum-Sudan with Hairy Vetch mixed in.

Table 3
Amounts of Organic Matter of Different Crops Remaining after Harvest in Same Year and Following

All numbers in lbs./acre

Crop	Under ground	Above ground	Total	Remains after one year
Rye	1100	3300	4400	1350
Oats	1250	3300	4550	1400
Potatoes	450	3150	3600	750
Beets	450	300	750	250
Cabbage	900	3600	4500	1000
Peas	350	1400	1750	400
Beans	350	1400	1750	400
Onions	270	180	450	130

Adapted from: Bemesting en meststoffen, by W.T. Rinsema PhD

All numbers in lbs./acre

Crop	Under ground	Above ground	Total	Remains after one year
Grass-clover				
1 year	2250	1350	3600	1050
2 years	6000	1350	7350	2300
3 years	9500	1350	10850	3600
Alfalfa				
1 year	1800	900	2700	700
2 years	2700	1350	4050	1200
3 years	4500	1350	5850	1850
10 tons of compost			6540	6000

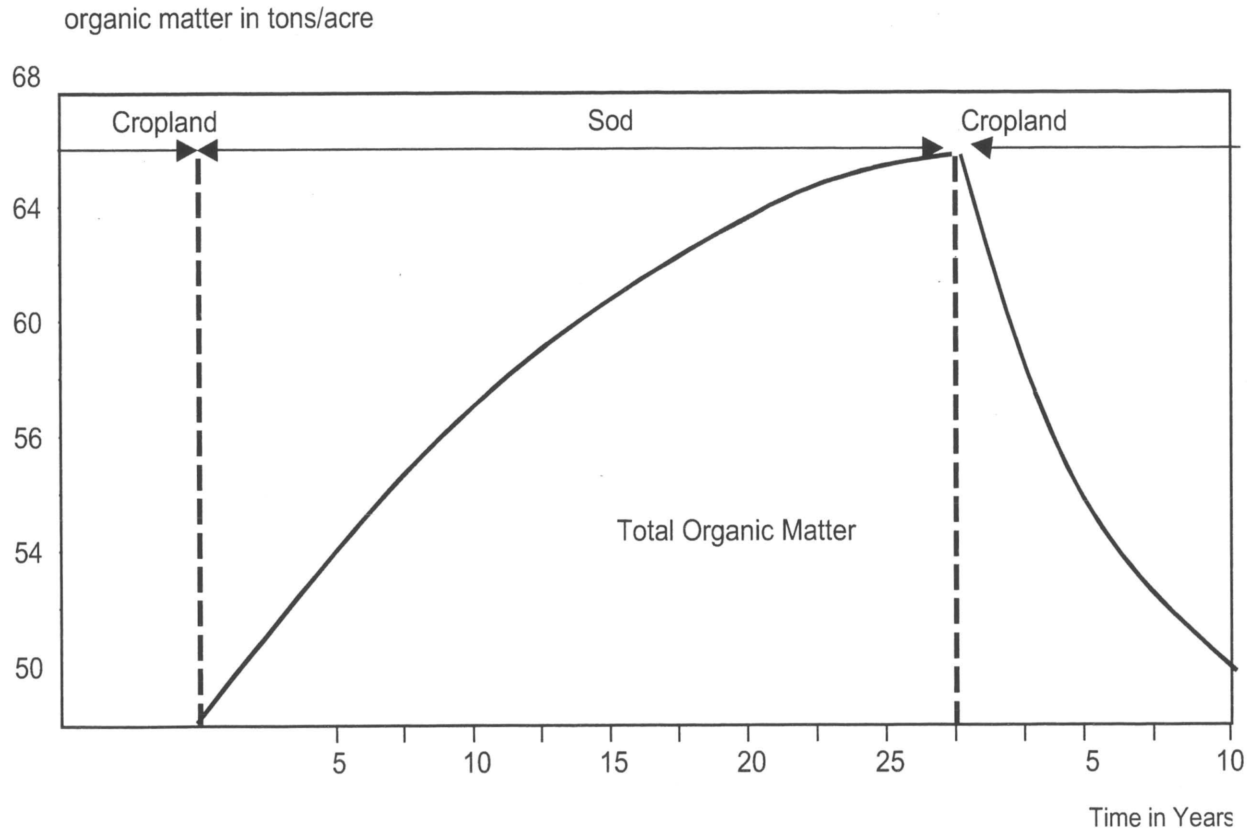

Figure 1

August

- Oats and Peas

September

- Rye with Hairy Vetch, Oats and peas.

October and November

- Rye

C. Crop rotation

Within the vegetable land have a system of permanent sections, that each contain eight beds. Permanent sections allow for keeping records of where the crops have grown and aid in exact planning. There is no guesswork in finding where last years crop was planted. The harvest lanes also serve as a means to get easily to the cash crops, a place to pull in the irrigation reel, and as pasture for the bees (since they mostly contain white clover).

Crop rotation is a tool used to break insect, weed, and disease pressure in the vegetable fields. There are many reports of increased yields of cash crops in fields that adopt rotations. In organic agriculture, we should not only rotate within the plant families of our cash crops but also include grasses and legumes in our rotation mix. As seen in the graph above, they fix decent amounts of organic matter and introduce a broad spectrum of soil life to the farm. They can also form a habitat for beneficial insects. They are a neutral crop in our rotation since they rarely host diseases that affect our cash crops. Proper incorporation and time to let the soil digest the plant matter is important. Too much raw organic matter can greatly affect the health of our cash crops in a negative way. Introduction of bare fallow periods in "neutral" years are effective in breaking up both weed cycles and incorporation of large amounts of plant matter.

At Roxbury the different plant families are:

- Apiaceae or Umbelliferae: carrots, parsnips, parsley, celery, dill, etc.
- Asteraceae or Compositae: all the lettuces, escarole, and certain cut flowers.
- Brassicaceae: all the Cole crops including broccoli, arugula, turnips, etc.
- Chenopodiaceae: all beets, chard, and spinach.
- Convolvulaceae: sweet potatoes
- Cucurbiticeae: all cucumbers, melons, squashes etc.
- Fabaceae or legumes: peas and beans.
- Liliaceae or Alliums: all the members of the onion family
- Poaceae: all grains including sweet corn.
- Rosaceae: strawberries
- Solanaceae: all nightshades, including eggplant, peppers, tomatoes, etc.

A few vegetables, herbs, or cut flowers are adopted in another family because they are relatively insignificant. A rule of thumb in any crop rotation is that no family follows itself in less than four years. Another guideline to use is to have plants with opposite nutrient requirements followed each other. And lastly crops that see this pressure more in the spring or fall alternate crops that show great weed pressure in the summer. This is done to offset the cycle in which those plants go to seed.

Use table 4 (page 54) as an example.

D. Mulches

Introduction of living mulches have become an important tool at Roxbury Farm to help create a good environment for our cash crops. The use of Dutch white clover in between the plastic has reduced Alternaria infections in tomatoes and keeps fruit clean in peppers, eggplant, cucumbers, melons, and squash. Over seeding of red clover in sweet corn and winter squash allowed for nitrogen fixing for next year's crop. We used to apply a lot of dead mulch like straw and leaves, but the dust and discomfort to our workers have limited the use of this to Strawberries and Garlic. As an alternative to straw, the beds with garlic can be covered with about six inches of leaves. Six inches is a

Table 4
Crop rotation

Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Greens Bare Fallow Oats and Peas	Carrots	Winter-Squash Red clover	Red Clover Bare fallow Oats and Peas	Potatoes Rye and Hairy Vetch	Rye and Hairy Vetch Bare Fallow Oats	Peas and Beans Oats and Peas
Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Red Clover	Red Clover Bare Fallow Oats and Peas	Early Broccoli / Cabbage Rye and Hairy Vetch	Rye and Hairy Vetch Bare Fallow Oats and Peas	Strawberries	Strawberries Bare fallow Oats and Peas	Spinach Lettuce
Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Oats with Sweet Clover	Sweet clover Sweet-corn Red Clover	Red Clover Bare Fallow Oats and peas	Potatoes Oats and Peas	Onions Rye and hairy Vetch	Rye and Hairy Vetch Fall Broccoli	Greens Lettuce

sufficient amount if you do not like to weed at all the following year. The garlic pops right through in the spring so this system works quite well if perennial weeds are not a problem.

E. Biodynamic preparations and compost teas

The use of Biodynamic preparation in the compost increases its ability to suppress plant diseases and introduce microorganisms needed for proper plant growth. Preparation 500 has shown to increase rooting depth of both cash and cover crops.

Research done by Elaine Ingham of the Soil Web has determined what microorganism help plants grow. She classified over 50,000 microorganisms in particular crops. After she tests a soil sample, she prescribes particular teas to inoculate the soil with the missing microorganism to provide for proper plant growth.

Within the management practices of the biodynamic preparations, we can distinguish between two different kinds of applications.

1. The compost preparations

The central thought behind the compost preparations is to give the compost a memory. When you make compost, the original material will transform into something completely new. Even chemical analysis cannot determine what the original material consisted of provided the original materials were of organic origin and the process of composting was done correctly. The word organic does include all compounds that are of organic origin, including chemicals.

There are six different compost preparations:

The **oak bark preparation** is made of finely ground-up oak bark that is put inside the skull of a freshly slaughtered cow. Great care is taken when the brains are removed to make place for the oak bark. Some people use a garden hose to flush out the brains but most likely, even though it appears to be gentle, it has the effect of flushing the essential membrane out as well. The membrane should be left intact, since the working of this membrane has the desired influence on the transformation of the oak bark. The skull is then placed in water that is preferably mucky and moving. This preparation will, if made properly, give the capacity to the compost to make the plants, grown on the composted soils, resistant to disease.

The **chamomile preparation** is made of dried chamomile flowers that are briefly soaked in lukewarm chamomile tea. This substance is then placed in freshly obtained intestines of a cow. Again, we see people clean these intestines out a lot with water, but we recommend leaving them the way they are to avoid damage. An intestine free from grass is ideal, but avoid any intestine from a cow that was grain-fed. The stuffed, so-called sausages are then placed in the soil and kept there over the winter. Great care is taken in what location the preparations are buried. The ideal location is where snow usually accumulates. The intestines will help the chamomile transform into a substance that will give the compost the ability to work in the processes in which potash and calcium are involved. The manure treated with the chamomile preparation shows greater stability of its nitrogen content.

The **yarrow preparation** is made with dried yarrow flowers that are briefly soaked in lukewarm yarrow tea. This substance is placed in the bladder of a stag that is enlarged by simply having it blown up like a balloon. This little bag is hung up on the south side of the barn during the summer months. In the fall it is buried the same as the chamomile preparation. The yarrow preparation gives the treated manure the ability to work in the soil in such a way so that it is capable of adsorbing minute quantities of trace minerals.

The **nettle preparation** is the easiest to make and can be used as a foliar spray. The nettle is harvested before the flowers go to seed. It is then directly placed in the earth, but not in direct contact with it. We place a layer of peat moss between the nettle and the moist earth. It is left there for a full season (summer and winter), and is then dug up and used as a preparation in the compost pile. Nettle does not need an animal organ. The nettle preparation has a strong relationship to the iron processes in the plant.

The **dandelion preparation** is made from the dried dandelion flowers. The flowers are picked in the morning. Only the flowers that have not yet fully opened are useful. When they are dried, mature flowers become seed. When we make this preparation in the fall, we start by soaking the flowers in lukewarm dandelion tea. The next step is to place this substance in little bags that we form out of the mesentery of a cow. The mesentery should be free of fat since that would inhibit proper transformation once it is placed in the soil. Also, when the bags are too large, there is a chance that the substance will turn into silage. A good size is about the amount of a baseball. These pockets are then buried like chamomile. The dandelion preparation is working through the compost in giving wisdom to the soil. All the positive influences from stream, pond, forest, meadow, and fields become available to the plant through the composted soil, giving the plant the faculty to attract these influences.

The last is the **valerian preparation**. Here the flowers are collected and the juice is pressed out. We are not blessed with having any significant amount of it grown around us, so I do not have any personal experience with making this one. But I can describe how to make it. First, make sure you have the real *Valeriana officinalis*. I have seen people using plants that look just like the valerian, but if it is not the real thing, it will not do what we are expecting. What you are after is the juice of the flowers. You can use a press to squeeze the juice out of the flowers. There are two variations available: one is fermented, which I prefer, and the other is bottled up the way it comes out of the press. The smell of the fermented valerian is wonderful. This preparation is made without an animal component like the nettle. The finished tincture is diluted in lukewarm water, stirred vigorously, and sprayed onto the compost pile. The valerian acts like a skin and contributes an element of warmth to the pile. In the spring, I take advantage of this ability by spraying the valerian tincture on tender plants to protect them from early morning frost.

2. The field sprays

The horn-manure and horn-silica preparations are both made with the horn of a cow. The horn of the bull is too soft. This is an interesting phenomena, which must fluster the Darwinist.

In the fall, we make **the Horn-Manure preparation**. The manure from a lactating cow is selected. The manure should have enough form so that the shape of the intestines is somewhat visible. But avoid using pies that start looking like sheep-manure. We place the manure into the horns and then bury them with the points of the horns sticking up to avoid rainwater from collecting in them. In the month of May, this preparation is dug up. The substance in the horns has by then become odorless. If there is a smell to it or if it still looks like manure, then you know that it has not been properly transformed. Before this preparation is applied to the fields as a spray, we have to dilute it in lukewarm water. About a baseball, size quantity per thirty gallons of water is sufficient. This is stirred vigorously in one direction until a vortex is formed, then the direction is reversed and stirred in the opposite direction to create another vortex, etc. The total time of stirring is one hour. The solution will now start smelling again, not like manure, but definitely alive. For filtering the liquid I found paint bags to be the best, the ones painters use to filter their paint. We do the filtering to avoid wasting time in the field cleaning spray-nozzles. Our Solo backpack sprayer covers about one acre if filled up. This is about three to three and a half gallons. This preparation is sprayed directly on the soil. If the soil has been worked, it can readily adsorb the positive influences of this preparation. Horn manure directly influences the way organic matter is transformed in the soil. Its positive influences are similar to what organic matter does to the soil. In general, we notice that horn manure works on germination, root development, and growth.

The Horn-Silica preparation makes use of a cow-horn again and finely ground Silica. This is then placed in the ground during the summer months. A much smaller quantity than the horn manure, no more than a pea-size amount, is stirred vigorously in 30 gallons of water for one hour. This solution is sprayed directly on the plants. The Horn Silica has a strong connection to the light and warmth forces of the summer. Its positive influences are similar to what the summer sun contributes to the plants. It slows down growth but increases the overall plant mass. Plants treated with this preparation will have better taste and keeping qualities. All preparations with the exception of Horn-Silica should be stored in peat moss, in a dark, cool, and damp place. Horn-Silica is left in a glass jar in a windowsill.

A study published in "the Journal for Science" compared organic, biodynamic and conventional research plots and found that the number and diversity on the biodynamic plots were far greater that the organic ones. This research that was conducted over a 21-year period showed that the biodynamic preparations greatly improve soil life. Another study performed by the University in Washington compared organic and biodynamic pastures in New Zealand. This study focused mostly on soil structure and rooting depth. The biodynamic plots had greater root systems and better soil structure.

Weed Management

Understanding Weed Biology

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What is a weed?

Weeds are commonly defined as plants that grow where they are not wanted. Although that definition has some practical utility, it fails to recognize that weeds share certain properties in common. Only a handful of the species you see around show up in farm fields and other places that you don't want them. Understanding what makes certain plants grow in human manipulated sites whereas others do not is a first step in planning management programs. From an ecological point of view "weeds are plants that are especially successful at colonizing disturbed, but potentially productive, sites, and at maintaining their abundance under conditions of repeated disturbance" (Mohler 2001).

Our crops are mostly annual species. That is, they complete their lifespan in less than one year. To make the habitat suitable for annuals, we eliminate the natural vegetation, which around here is broadleaf forest with a little hemlock and white pine. Annuals do not grow in forest conditions or in undisturbed prairie either, because little seedlings cannot compete with large, well-established plants that already occupy the site. So to make the land suitable for annuals, we clear off the woody plants, and plow up the soil to disrupt the perennial herbs. In ecological terms, plowed fields are perpetually held at year 0 of ecological succession. In other words, farming creates habitat that is suitable for species that specialize on highly and repeatedly disturbed conditions, namely weeds as defined above.

The basic thesis of this paper is that understanding the biology of weeds is a key to their control. The reason is that killing weeds without harming the crop depends on biological differences between the weeds and the crop. Weed biology becomes complicated, however, because weeds differ in their biology: there are many ways to be a weed. Fortunately, the variety of weeds can be grouped into a few categories based on the life-history of the species. That is, for management purposes, weeds can be grouped according to how long various life stages live, and how the plant reproduces. At the broadest scale, weeds can be divided into annuals and perennials, and I will begin with the perennials.

Perennial weeds

Types of perennials

A perennial weed is a weed that persists in the vegetative state for more that one year. The types of perennials can be classified according to whether they reproduce vegetatively, and the nature of the perennating organ (Table 1, page 60).

Table 1
Types of perennial weeds and examples.

Nature of the root system	Examples
Stationary perennials	
Taprooted	Dandelion, burdock
Fibrous rooted	Broadleaf plantain, tall buttercup
Wandering perennials	
Bulb or tuber	Yellow nutsedge, wild garlic
Shallow storage organ	Quackgrass, johnsongrass
Deep storage organ	Common bindweed, Canada thistle

Stationary perennials do not reproduce vegetatively, except occasionally when the taproot or root crown is broken by a tillage implement. Most reproduction is by seed, and they commonly produce copious quantities of seeds that typically persist in the soil for many decades. Primarily, they are weeds of pastures, hay meadows and waste ground. When the soil is regularly tilled, they tend to disappear after a year or two, except for species like dandelion that regularly blow in from adjacent habitats. The reason for the absence of stationary perennials on tilled ground is two-fold. First, since the root system is not well built for vegetative propagation, soil disturbance tends to damage the storage organs and kill the plants. Second, stationary perennials are usually not very competitive the first year because they are putting energy into building the taproot or the root crown so that they will have the resources to survive the winter. They are often highly competitive in subsequent years, however, because they have these substantial reserves with which to rapidly establish in the spring and compete with any annuals present. These qualities explain both why they are usually minimal problems in organic annual agriculture, and why they can reach substantial abundance in pastures, hayfields, and conventional no-till fields.

Wandering perennials reproduce primarily by vegetative reproduction. They spread underground by thickened storage roots or by horizontal underground stems (rhizomes). A few species also produce bulbs or tubers that are the overwintering storage organ for the plant. Although many of the wandering perennials do produce seeds under some conditions, typically seed production is low, and the seeds usually do not persist long in the soil. Most of these species do not self-pollinate (Mulligan and Findlay 1970), and consequently, if the population consists of a single clone, no seed production is possible. For example, only about one yellow nutsedge population in 10 produces viable seeds (Mulligan and Junkins 1976). For wandering perennials, seed production is mainly a way to spread the species around rather than a way of maintaining the population at a particular site. For that, the plant relies on sprouts from the root or rhizome system.

Below-ground apical dominance in perennial weeds

The key fact about the underground organs of perennial weeds is that they show what botanists refer to as apical dominance (Håkansson 1982). You are familiar with this phenomenon in the above ground shoots of plants: if you prune off the end of a branch, the nearest lateral bud (or buds if the leaves are opposite) will begin to elongate much sooner than they would otherwise. This occurs because the growing point of the branch produces hormones (auxins) that suppress the growth of the lateral buds. When the growing point is gone, so is the suppression and the lateral buds grow. They then produce auxins that suppress the growth of buds further down the stem.

Essentially the same phenomenon occurs in the root or rhizome system of wandering perennials (Figure 1). The above ground shoots emerge from the terminal bud of the rhizome or storage root. If this shoot is removed, then the next bud in line is released and a new shoot grows up to take the place of the one that was killed. More critically, if the root or rhizome is broken into pieces by a tillage implement, then the terminal bud on each piece will be released from suppression, and you will see lots of sprouts. Each of these sprouts

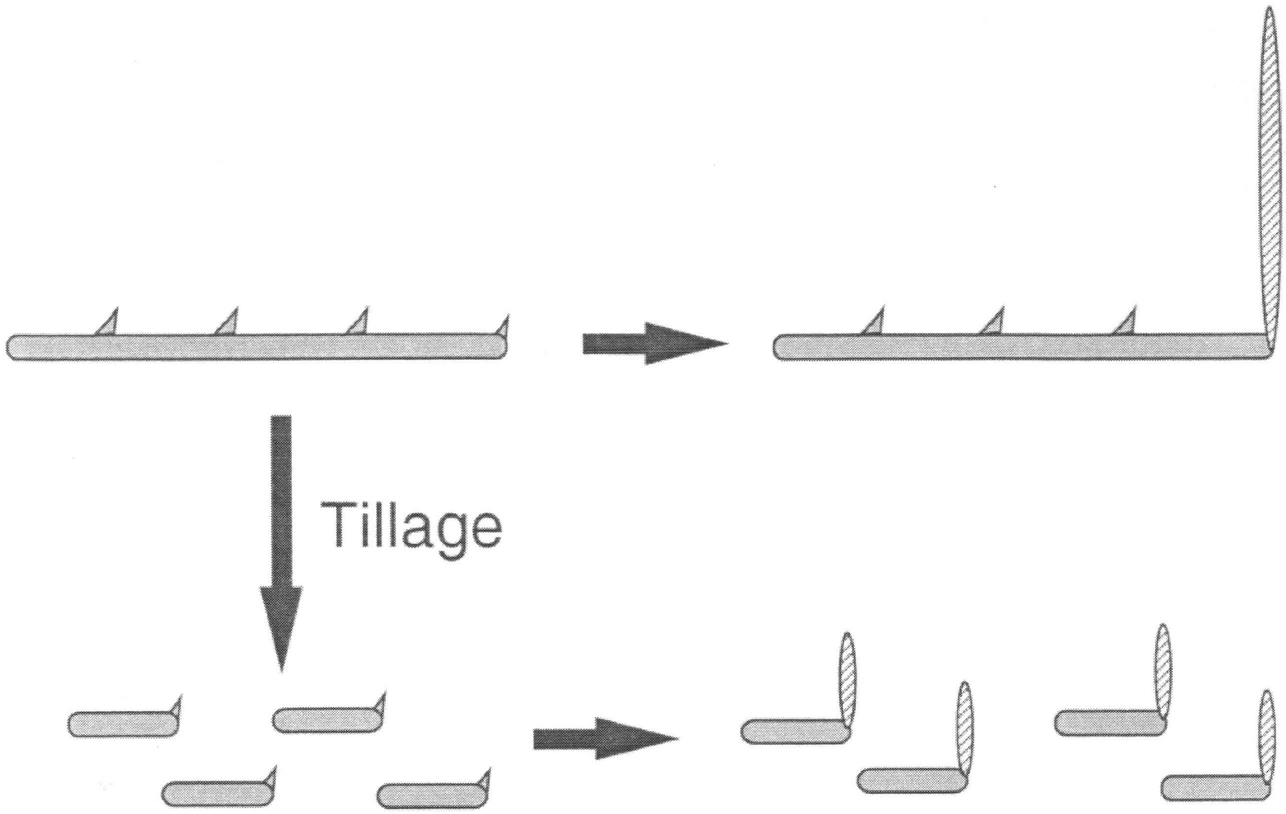

Figure 1
Due to hormonal suppression of most buds by the terminal shoot (apical dominance), breakage of rhizomes or perennating roots results in an increase in the number of shoots, but a decrease in the resources available to each.

will be relatively weak, however, because it is backed up by small reserves of carbohydrate.

From a management perspective, this behavioral response of wandering perennials is either good or bad depending on what you do. If you till up a stand of quackgrass and then plant onions, you probably will have worsened your weed problems. In contrast, if the field is tilled, the fragments allowed to sprout, and then you cultivate out the sprouts, you will have seriously depleted the already weakened rhizome fragments. Repeating this process, or planting a fast growing, highly competitive crop will further suppress the weed (Håkansson 1971). Since quackgrass is a cool season grass, sowing a fall cover crop of rye or winter wheat at a high density is pretty effective. Note here that any one of the several measures taken alone would probably be insufficient to control the weed. Just fragmenting the rhizomes with tillage would likely increase quackgrass density; cultivation without using a prior tillage practice that severely fragmented the weed would just spread the infestation around. Competitive crops are always helpful, but rarely sufficient to control perennial weeds unless the weeds have previously been set back by tillage and cultivation.

Not all wandering perennial weeds sprout immediately after fragmentation, but that is the usual pattern, and most of the wandering perennials in the Northeast behave in this way. Some species, notably the common and hedge bindweed and Canada thistle are not easily broken up by tillage because their root or rhizome systems are so deep in the soil. To get at hedge bindweed or Canada thistle requires subsoiling equipment, and on a deep soil, much of the root system of common bindweed will be completely out of reach. The only alternative then is to try to exhaust the whole mass of the root or rhizome system by repeated killing of the emerged shoots. For many wandering perennials, the shoot begins transporting food back to the root system at about the 3 to 4 leaf stage, so that is a good time to cultivate. Before that, the shoot is a net drain on the perennating storage organs.

Weed seeds

Germination cues

Annual species are plants in which the individual lives for less than one year. These species necessarily reproduce by seeds. Because reproduction by seeds is essential for annuals and they live in a frequently disturbed environment, they produce many small seeds. They have been selected to produce many seeds so as to spread the risk of death by disturbance over many offspring. Most weeds die young so they make a lot of seeds to compensate for that mortality. Since each individual plant has limited resources, producing many seeds necessarily means that the seeds are small. I will return to the consequences of small seed size repeatedly. Another way in which annuals manage the riskiness of specialization on disturbed environments is by recognizing the most favorable conditions for germination.

Since most weed species have small seeds, most weed seedlings lack the resources to be able to grow up from deep in the soil and most emergence is from seeds near the soil surface (Chancellor 1964, Mohler 1993). Nearly all individuals of small seeded weeds (and most weeds in the northeastern U.S.A. weigh less than 2 mg), emerge from within the top inch of soil (Figure 2, lambsquarters, redroot pigweed). Even relatively large seeded weeds like velvetleaf (9.5 mg) mostly emerge from within the top 2 inches of soil (Figure 2). Since seeds that germinate deep in the soil die, weed seeds that recognize when they are near the soil surface have been favored by natural selection.

Since most weeds have small seeds, they make tiny seedlings. A lambsquarters seedling when it first comes up has cotyledons that are about 1/32 of an inch wide and 1/8 inch long. Such tiny plants have no chance of survival in established perennial vegetation like a hay meadow or forest. Consequently, most weeds have been selected for physiological mechanisms that allow the seeds to recognize that competing vegetation is limited or absent. In natural conditions, the main thing that eliminates perennial vegetation is soil disturbance, usually by animal activity. So some of the signals that cue germination are related to soil disturbance, whereas others are simply related to the absence of vegetation or near surface conditions. Few of the cues are absolute requirements for any species. Rather, they change the percentage of seeds that germinate and work together to signal the appropriate conditions for germination. No species responds to all of the cues discussed below, but most respond to several.

The most common cue that weeds respond to is light. Most weed species show increased percentage germination in light relative to darkness (Table 2, page 64). Some species, like common chickweed, germinate in the dark when first shed from the plant, but after burial in soil, show greatly increased germination if exposed to light (Wesson and Waring 1969). The amount of light required to stimulate germination is sometimes amazingly small. For example, redroot pigweed will germinate in response to a few thousandths of a second of sunlight (Gallagher and Cardina 1998). Thus, if a seed comes to the surface during tillage or cultivation and then is buried again it may be stimulated to germinate. This is why tillage in the dark often reduces the density of weed seedlings (Ascard 1994, Scopel et al 1994, Buhler 1997). Dark tillage is no panacea, however, since weeds respond to other cues as well.

Even the type of light affects germination. Red light stimulates germination. Light filtered through a plant canopy is green; which is to say, it is depleted in the red wavelengths. Thus, if a light sensitive seed is exposed to green light, the seed senses that it is surrounded by competing vegetation, and germination is inhibited (Górski 1975, King 1975). Seeds behave oppositely to cars: they stop on green and go on red, and ordinary sunlight is full of red wavelengths.

Another factor that stimulates germination of some weed species is high soil temperature. For example, redroot pigweed germinates best at 86° to 104° F (Table 3, page 64). Soil temperatures that high are rarely achieved except near the surface of bare soil. Common purslane germinates best at similarly high temperatures (Vengris et al. 1972).

When soil is bare, the high temperatures obtained during the day are often not retained during the night because the soil cools by emitting infrared radiation to

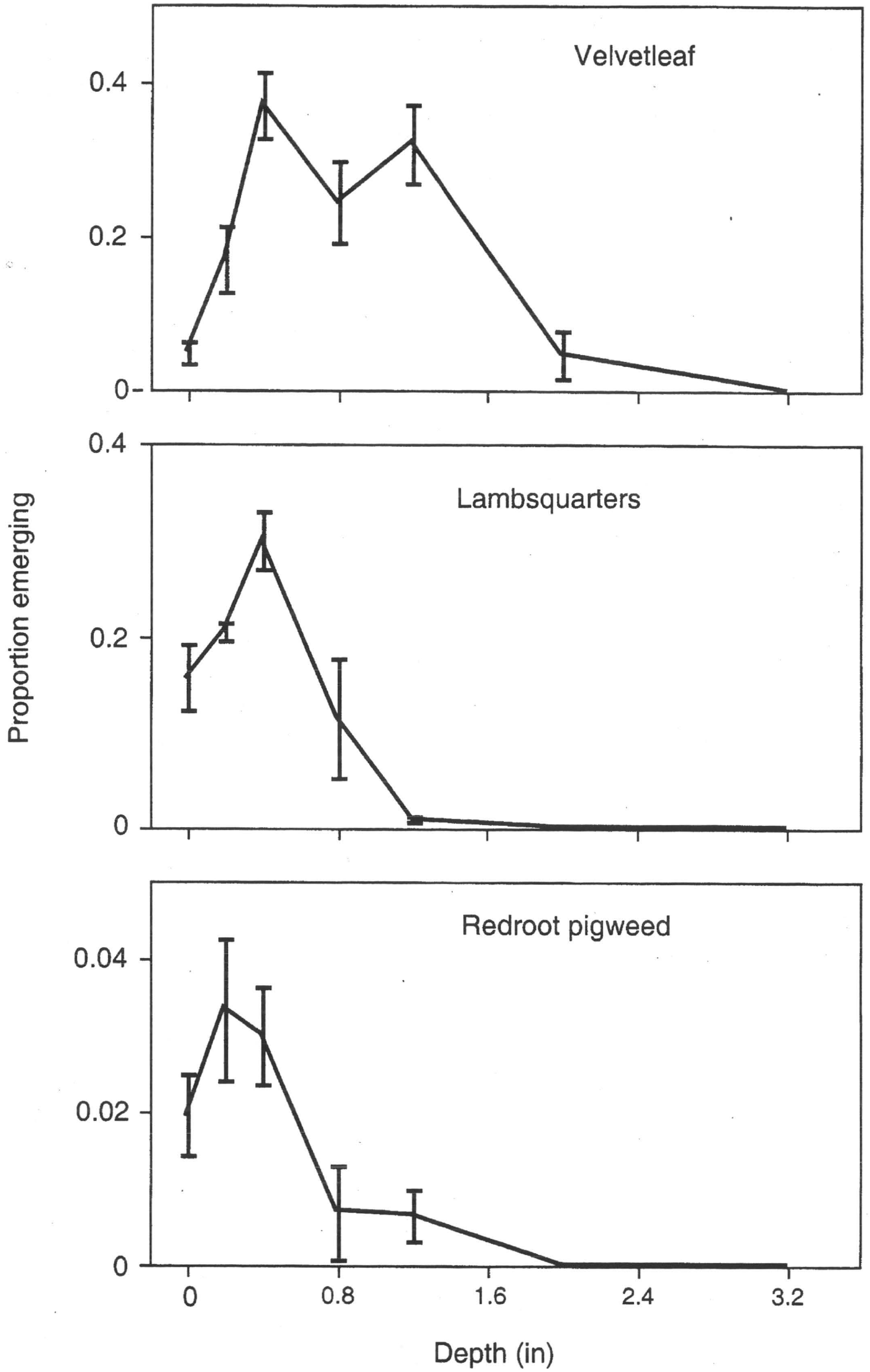

Figure 2

Proportion of seeds planted at a given depth that emerged as seedlings for three common weed species

Seeds were cold treated at 40° F in field soil for approximately two months and then placed at the indicated depth in early spring without exposure to light.

(Redrawn from Mohler, in preparation)

Table 2
Germination response of some common weeds to light.

	% Germination		
Species	Light	Dark	Reference
Redroot pigweed	98	14	Kigel (1994)
Annual bluegrass	89	1	Froud-Williams (1985)
Common purslane	28	12	Povilitis (1956)

Table 3
Percentage germination of redroot pigweed seeds in response to temperature in five northern states. Computed from McWilliams et al. (1968)

Location	Populations tested	68° F	95° F
Michigan	1	0	90
Minnesota	1	15	100
New York	5	6	93
North Dakota	17	23	80
Vermont	1	15	93

the sky. Consequently, surface soil temperature fluctuates much more for bare soil than for soil covered by living or dead plants (Teasdale and Mohler 1993). Many weed species use this temperature fluctuation as a means for recognizing bare ground (Table 4). For curlydock, temperature fluctuation is nearly an absolute requirement (Totterdell and Roberts 1980). Provided the seeds are exposed to light, percentage germination at any constant temperature from 35° to 95° F is near 0 but a variety of different fluctuating temperature regimens give 100% germination.

Weed seeds also germinate in response to chemical cues associated with soil disturbances like tillage. Aeration and warming of the soil by tillage stimulates microbial decomposition of soil organic matter. This releases nitrogenous compounds that specialized bacteria turn into nitrate. Nitrate in the soil solution stimulates germination of some weed species, like lambsquarters (Roberts and Benjamin 1979). In addition to the problems chemical fertilizers create for the soil, this is another good reason to avoid them.

When diffusion of gasses is limited, for example, deep in the soil or in the interior of soil aggregates, oxygen may limit the respiration of seeds. Seeds are alive, and moist seeds are particularly active metabolically. When oxygen is limited, respiration cannot take carbohydrates all the way to carbon dioxide and water. Instead the seed produces volatile organic compounds like ethanol and acetone. These leak from the seed and build up in its vicinity. These compounds indicate a terrible environment for establishment, and they inhibit germination of some species (e.g., velvetleaf). When the soil is stirred by tillage, the volatile products of anaerobic respiration are vented to the breezes and the seeds germinate in response to their absence. I suspect this germination cueing mechanism is quite common, but few weed species have been tested. The seeds are apparently not responding to oxygen itself since flushing the soil with pure nitrogen will prompt germination as readily as flushing with air (Holm 1972).

As can be seen from Tables 2 to 4 and the discussion above, germination response to any one particular cue

Table 4
Effects of constant and fluctuating temperature on germination of common chickweed seeds in the dark. In the alternating temperature treatment, the high temperature was held for 8 h and the low temperature for 16 h. Extracted from Roberts and Lockett (1975).

Regimen	Temperature (°F)	Germination (%)
Extreme alternating	50/86	98
Constant low	50	48
Constant high	86	2
Constant middle	68	65
Low temperature alternating	59/77	97
Constant low	59	77
Constant high	77	12
Constant middle	68	65
High temperature alternating	68/86	84
Constant low	68	65
Constant high	86	2
Constant middle	77	12
Mean of alternating		96
Mean of middle		47

is rarely absolute. Rather the cues act cumulatively, and one cue can often replace another (Vincent and Roberts 1977, Roberts and Benjamin 1979). If no cues are present, a few seeds may germinate, essentially by mistake. If several cues are present, most seeds will germinate. If just one or two cues are present, some fraction will germinate. This partial response to multiple cues essentially hedges the bet each weed species is making about the suitability of the environment for establishment and growth. If the environment is maybe OK but not perfect, some individuals will germinate whereas others in a slightly different physiological state or microenvironment will wait, perhaps for years.

The management consequences of weed seed response to germination cues associated with near surface tilled conditions is that you can often trick weeds into germinating on command. A short period of bare fallow before or after the crop signals the weeds to germinate but gives you the opportunity to then cultivate and get rid of them.

Season of germination

All plants that live in a seasonal climate like the Northeast face the problem of knowing what time of year to germinate, and weeds are no exception. Every season has weeds that are specialized on that time of year (Figure 3, page 66).

A few weed species, like velvetleaf and common bindweed have hard seed coats that prevent the seeds from absorbing water. The seed coat changes with exposure to soil conditions: organic acids, microorganisms and freeze-thaw cycles produce cracks or open specialized pores that allow water to enter the seed. Then, if the environmental cues are right, the seed germinates. Since winter represents a long period for these changes to take place, species with hard seeds usually germinate and emerge mostly in the spring with a trickle of germination through the rest of the growing season.

Most weed species, including many with hard seed coats, have physiological mechanisms that control

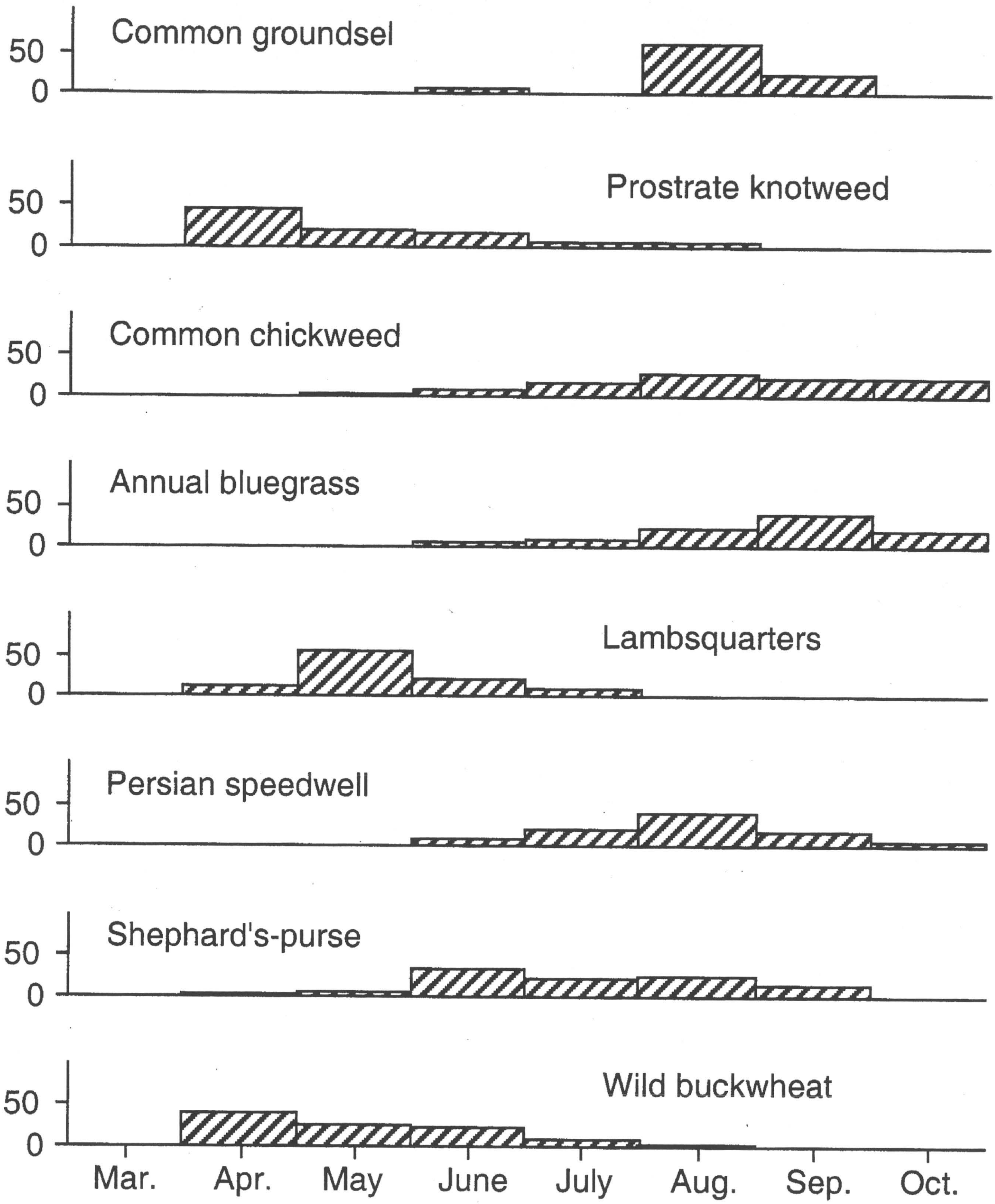

Figure 3
Seasonality of seedling emergence for eight weeds in the southern United Kingdom
(Redrawn from Mohler 2001 based on data from Lawson et al 1974)

when the seeds germinate. Some species will germinate immediately after falling from the parent plant, if the appropriate cues are present. These species follow the path from no dormancy to immediate germination shown on Figure 4.

Many weed species, however, cycle between a dormant and nondormant state during the course of the year (Baskin and Baskin 1985). For example, common ragweed is primarily a spring germinating species. Seeds are shed from the parent plant in a dormant state. As they are exposed to cold temperatures during the winter, they become "conditionally dormant." That is, if conditions are just right, they will germinate. After a longer exposure to cold (4-6 weeks) they lose dormancy and will germinate under a wide range of conditions. So when the weather warms in the spring you often see a flush of ragweed seedlings. However, if the appropriate germination cues are absent, and the seed cooks at summer temperatures, it will again become dormant (Baskin and Baskin 1980). That is, it will be unable to germinate even if given optimal germination conditions. Ragweed takes several months to mature and this mechanism essentially protects the seeds from germinating in late summer or fall when successful reproduction would be unlikely.

Subtleties abound with the annual germination-dormancy cycle. Shepherd's-purse, for example, behaves much like ragweed, but with a slight difference. It germinates best at relatively low temperatures and will germinate in the spring. Unlike ragweed, however, shepherd's-purse only becomes conditionally dormant at high temperatures (Baskin and Baskin 1989). Consequently, when temperatures cool in the fall, more seeds will germinate, including some of those shed the previous spring. Thus the species behaves as both a spring and a winter annual in the Northeast, and in cool, wet summers it will germinate all summer.

The management consequences of weed seasonality relates to crop rotation. A spring germinating species will fare poorly in a fall planted crop like spelt or a rye cover crop because the new seedlings will have to compete with a dense stand of well established plants. Similarly, summer germinating weeds like purslane will do

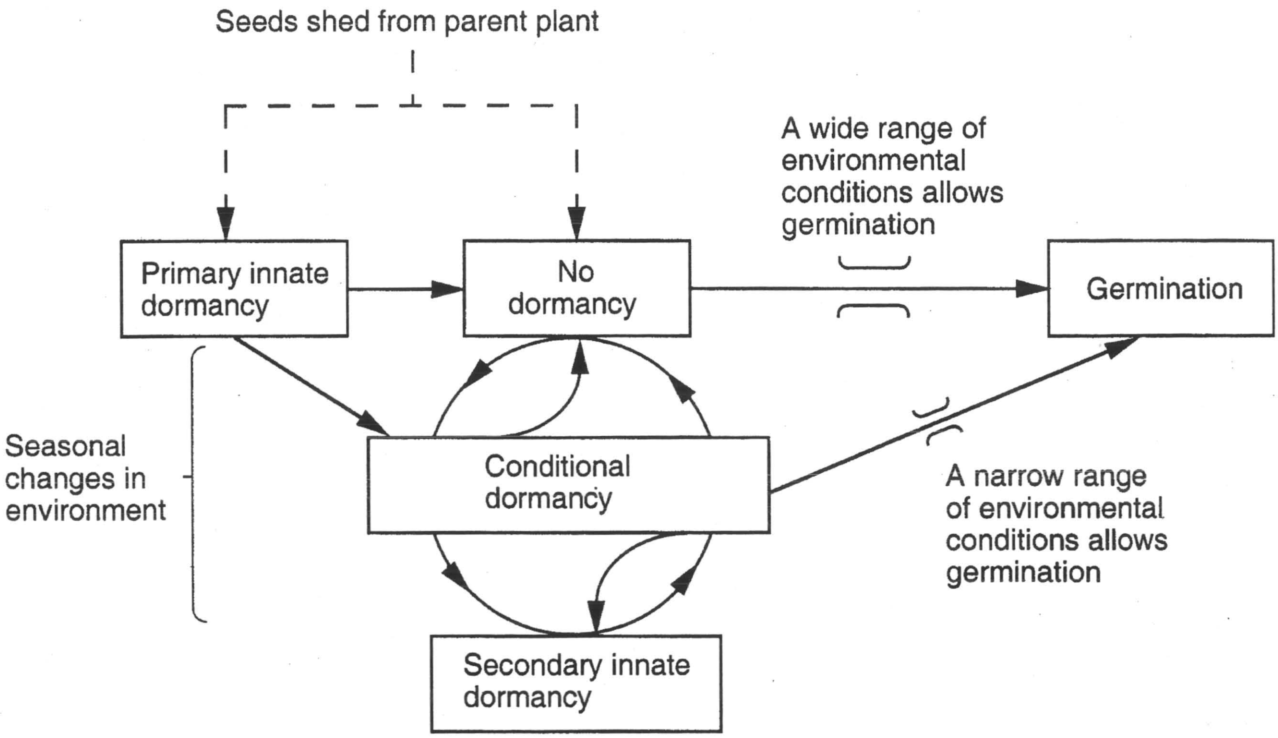

Figure 4
Relationships among states of seed dormancy for weed seeds with physiologically controlled dormancy
(reprinted with permission of Cambridge University Press; from Mohler 2001, Ecological Management of Agricultural Weeds)

poorly in a good stand of a long season crop like soybeans. In both these cases, many of the weed seeds will not even germinate because the appropriate cues are not there at the right time. Natural processes then have another year in which to kill off the seeds. The extreme of this latter process occurs when the ground is planted with a sod crop for several years. Weed seeds under the sod do not receive the appropriate germination cues, and any that germinate accidentally are killed by competition or mowing. Hairy galinsoga is the worst weed problem many vegetable growers face because they grow annual crops every year. In contrast, I have never seen a dairy farm with a galinsoga problem because they rotate annual crops with sod crops, and the galinsoga seeds die out during the sod portion of the cycle.

Seed longevity

This brings me to the topic of seed mortality and its converse, seed longevity. Unlike humans, weed seeds do not have a more or less given lifespan. Rather, their probability of death remains about equal each year, assuming the environment is constant. That is, weather, management practices, or other conditions may lead to greater or lesser mortality in any given year, but if conditions are constant over a series of years, then a constant percentage of seeds will tend to die each year. If seeds took out life insurance, the annual payment for an 80 year old would be the same as for a 20 year old. Consequently, asking how long a particular species lasts in the soil is nearly meaningless.

Various species differ in their rate of death (Table 5). Some species survive well, with only a small percentage dying each year. In undisturbed agricultural soil the death rate of buried lambsquarters was less than 10%/year in the particular experiment shown in Table 5. In really favorable conditions the death rate is probably even lower: viable lambsquarters seeds have been recovered from under the foundations of medieval European buildings. For other species, like common groundsel and hairy galinsoga, the seeds die off rapidly, even when undisturbed.

Of course, in an agricultural field the seeds are rarely undisturbed. Rather, the field is tilled, a seedbed prepared and often the soil is cultivated later in the season. Debris may be disked under in the fall or the ground chisel plowed in preparation for the next season. As I discussed previously, this soil disturbance cues seeds to germinate. Some of these will appear as seedlings and have to be dealt with, but many others never make it out of the soil due to attack by soil organisms or being buried too deeply for emergence. Regardless of its other benefits or problems, tillage and cultivation tends to deplete the soil seed bank.

Seed size and crop-weed competition

I have mentioned several times that most weeds have very small seeds. In particular their seeds are small relative to the seeds of most crop species (Table 6). This size differential gives the crops a critical head start over the weeds. Of course, some vegetable crops also have small seeds (for example, lettuce, cole crops, tomato, pepper). On organic farms, the great majority of small seeded vegetable species are transplanted into the field, which gives them the same sort of head start that the large seeded crops have over the weeds. A conventional vegetable grower may direct seed cole crops, tomatoes or leaks and use herbicides to control the early weeds. For an organic farmer, the extra labor of weeding a direct seeding is likely to exceed the cost of growing transplants.

The differential in seed size has several consequences. First, it makes within row weeding possible. For example, you can take a tine weeder over many large seeded crops before they are up or while they are still

Table 5
Seed mortality as percentage loss per year in cultivated and uncultivated soil over a 5 year period. Calculated from Roberts and Feast (1972).

Species	Cultivated[a]	Uncultivated
Shepherd's-purse	43	24
Lambsquarters	31	8
Black medic	30	22
Annual bluegrass	26	22
Prostrate knotweed	47	16
Wild buckwheat	50	25
Common groundsel	High	45
Common chickweed	54	32
Persian speedwell	54	22
Field violet	40	15

a Soil was stirred four times per year.

small without killing the crop. The crop is rooted below the depth of penetration of the weeder (usually about 1 inch), but as I pointed out earlier, most of the weeds are emerging from the top inch of soil and are therefore susceptible. All in-row weeding tools rely on this differential between the size of the crop and the size of the weeds, including rotary hoes, Buddingh finger weeders and Bezzerides torsion weeders, spring hoes and spinners.

Another important consequence of the seed size difference between crops and weeds is that crops can emerge through substantial layers of mulch whereas weeds are suppressed (Figure 5). If our weeds had seeds the size of corn or beans, mulch would be a completely useless way to suppress them.

Finally, because the crop usually gets a head start over the weeds, with some planning, it is often possible to

Table 6
Propagule weight for the five most common annual weeds of field crops in New York state and for the five annual field crops with the greatest acreage in New York State. Weeds and crops are listed in order of seed size not importance or acreage. Excerpted from Mohler (1996).

Weed species	Propagule weight (mg)[a]	Crop species	Propagule weight (mg)[a]
Velvetleaf	9.5	Corn	250
Common ragweed	4.4	Soybean	220
Wild mustard	2.2	Wheat	39
Lambsquarters	0.74	Oat	35
Redroot pigweed	0.44	Rye	27

a American units of weight do not include familiar units appropriate for expressing seed weights. One lettuce seed weighs about 1 mg.

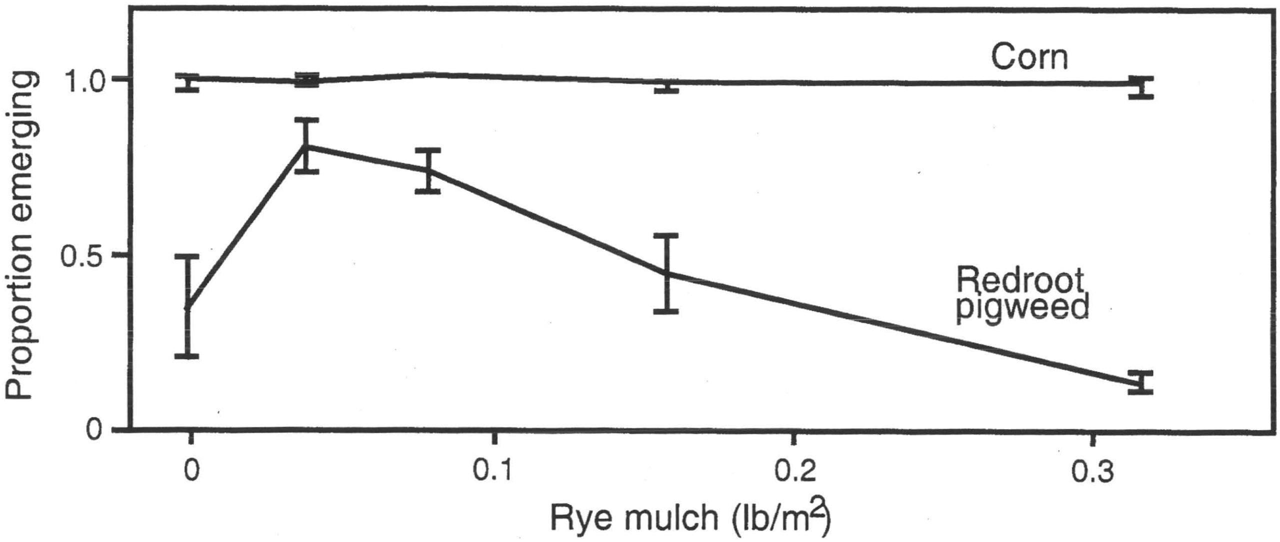

Figure 5
Proportion of a large seeded crop (corn) and a small seeded weed (redroot pigweed) that emerged through various rates of rye straw applied as a mulch at planting. Each species was planted at a depth that had produced high emergence rates without mulch in previous experiments.
(Mohler, unpublished data)

keep the crop in a competitively superior position. Weeds are gap fillers – they are adapted to grow rapidly in the absence of competitors, and with few exceptions they grow poorly in shade. Sometimes the crop can be made more competitive by using a higher planting density, or planting multiple rows on a bed. If that is practical, then the crop canopy will close sooner, and the weeds will be at a greater disadvantage. Similarly, if the row has a skip, that is an opportunity for weed growth. Consequently, skips should be replanted. If the crop stand is poor over a large area, it may be cheaper to disk the crop under and replant or plant some other crop rather than cope with the extra expense of weed control. In my experience, something like 80% or more of weed control comes from crop competition rather than from cultivating or hand weeding. Make sure there is always a crop or cover crop there to provide that control.

Another trick to increase crop competitiveness is to direct water or nutrients toward the crop rather than broadcasting them generally over the field. Drip irrigation favors the crop relative to the weeds more than sprinkler irrigation because the water is released near the crop roots rather than over the whole field. Similarly, if a concentrated nutrient source like bone or blood meal is used to give the crop a boost, it is best to weed first, and band or sidedress the material near the crop. Most weeds are luxury feeders that will rapidly take up and concentrate mineral nutrients. Several studies have shown that weeds often have one to three times higher concentrations of N, P and K than the crops with which they are competing (Vengris et al. 1953, Qasem 1992). Some studies have shown that the slow release of nutrients from green manure or compost favors growth of crops relative to weeds (Dyck et al. 1995, Gallandt et al. 1998). This makes sense biologically, but too few studies have been done to make a generalization yet.

The problem with the initial size advantage of crops is that it is usually short lived. This is because most weeds have a higher relative growth rate than the crops with which they compete. This is partially due to the difference in seed size and partially due to differences in their growth forms and ability to take up nutrients. The relation of seed size to growth rate is particularly interesting (Table 7). Large seeds make large seedlings, and these grow faster in an absolute sense of weight of tissue added per day. However, larger plants have a higher percentage of tissue in non-photosynthetic parts like roots and stems relative to leaves. Consequently, the relative growth rate (that is, weight gain/unit weight/day) of species with large seedlings is less. A financial analogy would be two individuals, one of which (the crop) starts with more capital, but the other (the weed) invest at a higher rate of compound interest. Consequently, weeds that start out so small you can barely see them may eventually overtop the crops. This is why early weeding while the weeds are still tiny and easy to kill is so critical to a good organic weed control program.

Seed production

As I mentioned in the introduction, weeds have adapted to frequent disturbance by partitioning their reproductive output into lots of small seeds rather than a few large ones. This spreads risk and increases the chance that one or more seeds will grow to maturity.

The seed production capacity of weeds is astounding. A big lambsquarters or barnyardgrass plant can produce over 100,000 seeds. I once sampled a large, open grown pigweed that produced an estimated 250,000 seeds. A student of mine grew some hairy galinsoga in pots and carefully collected the seeds as they formed. Plants a little bigger than a basketball produced 40,000 seeds apiece.

I will emphasize that big plants have many more seeds than small plants. Compare, say, two redroot pigweed plants. If one is twice as tall, or twice as big around, it will not have twice as many seeds but rather, many, many times more seeds (Mohler and Callaway 1995). Consequently, removing large individual weeds is important for long-term weed management, even if it means hand rogueing the field. Fortunately, most weed seeds come from a few large plants (Figure 6). The little plants may produce enough seeds to maintain the population, but they are unlikely to create a rapid increase in weed density.

Also, when rogueing mature or nearly mature plants, be sure to remove them from the field. Many weed species can set seeds even after they have been uprooted if the flowers have opened. Dandelion flowers will set seeds even if they have been severed from the plant and incorporated into the soil!

Table 7
Seed weight, initial growth rate, and relative growth rate of five annual plants with seeds of various sizes. Excerpted from Siebert and Pierce (1993)

Species	Seed weight (mg)[a]	Initial growth rate (mg/d)	Relative growth rate (mg/mg/d)
Lambsquarters	0.41	0.14	0.36
Velvetleaf	7.8	1.9	0.24
Cocklebur	38	7.1	0.19
Sunflower	61	12	0.20
Soybean	158	24	0.16

a *American units of weight do not include familiar units appropriate for expressing seed weights. One lettuce seed weighs about 1 mg.*

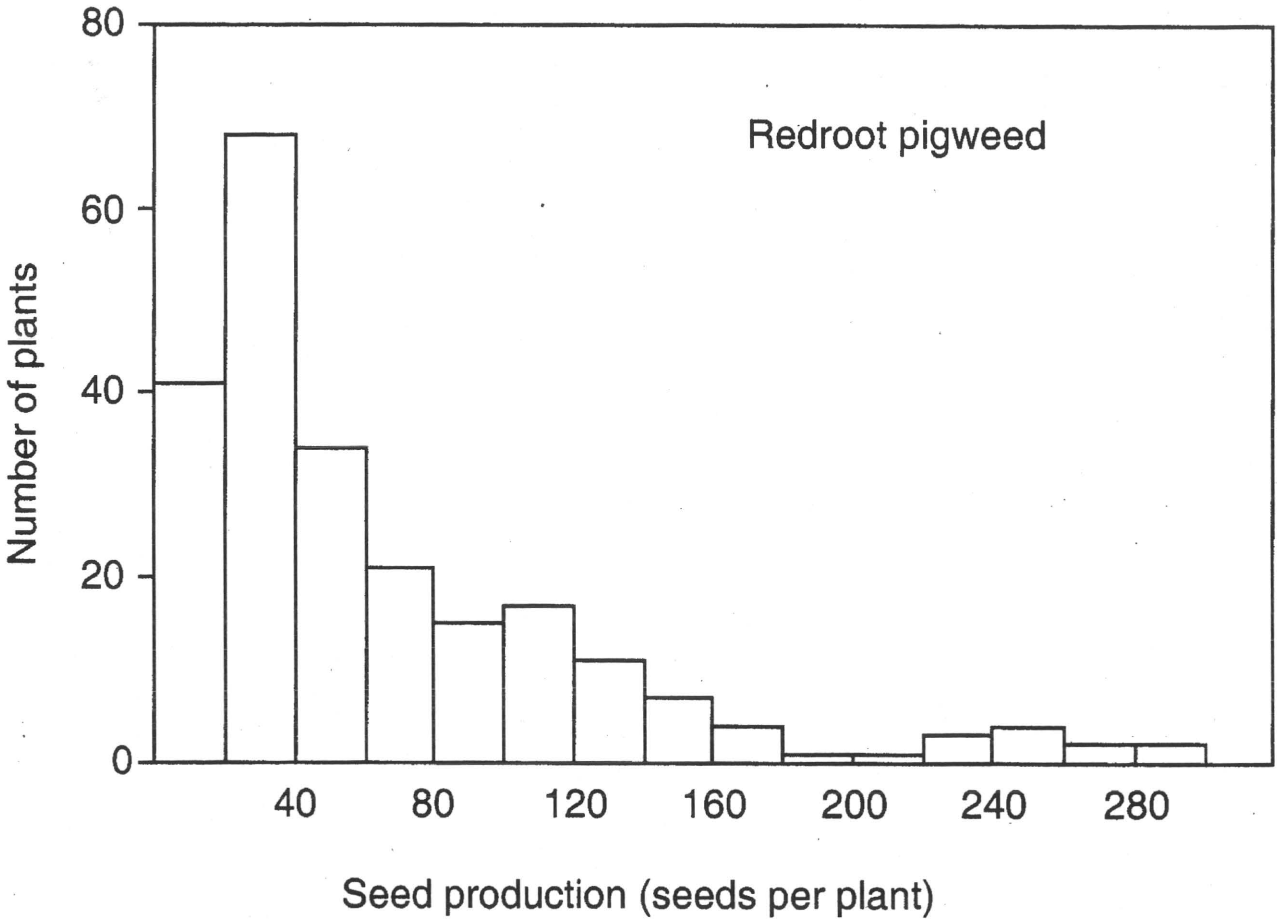

Figure 6
Distribution of estimated seed production in a population of 231 redroot pigweed plants growing in sweet corn. Sweet corn was planted in early June and weeds emerged primarily in July after the dissipation of atrazine
(Redrawn from Mohler 2001, see Mohler and Callaway 1995)

Seed dispersal

Many plant species have specializations that encourage the dispersal of seeds by animals or by wind, including fleshy fruits, hooks, bristles, fluffy hairs, and wings. A substantial portion of the perennial weeds found in pastures and hay meadows possess such specializations. This is reasonable since animals are regularly in contact with these plants, and vegetative reproduction insures the persistence of the population even if many wind-dispersed seeds are blown into unfavorable habitats.

In contrast, few weeds of regularly tilled fields show any of these adaptations. On the contrary, most weeds of tilled ground have small, round, nearly smooth seeds that fall within a few feet of the parent plant. This poses an apparent contradiction: some of the world's most widespread species appear to lack capacity for dispersal. The resolution to the contradiction is, of course, that they have been moved around by people. They move in poorly cleaned crop seed, in feed grain and then in the manure when it is spread, on tractor tires and tillage machinery, and on combines and other harvesting equipment (Mohler 2001).

An interesting bit of biology lurks within this dispersal by humans. As discussed previously, most species of weed seeds are highly resistant to decomposition. They persist in the soil for long periods, and consequently can build up to high densities that make dispersal on machinery likely. Moreover, most species pass unharmed through the digestive tract of large grazing mammals. Prior to human agriculture they probably thrived best in animal disturbed habitats (bare ground and high fertility), and moved about within the guts and in soil caked on the fur of migrating animal herds. I can easily imagine ragweed seeds moving many miles caked to the fur of wandering bison or mammoths.

Probably, however, none of the weeds on your farms reached there in prehistoric times. The land survey records indicate that over 97% of the landscape of western New York was forested in the 1790s, and most of the balance was in wetlands, blowdowns and recent burns (Marks and Gardescue 1992). With few exceptions, agricultural weeds do not grow in forests or wetlands, even when they are disturbed by natural processes. Rather, these weeds mostly arrived on your farms after Europeans settled the land. The critical question is, are new weed species still arriving on your farm?

The spread of velvetleaf makes a good example of the way civilization moves weed species around the landscape. The "Flora of the Cayuga Lake Basin, New York" (Wiegand and Eames 1925) lists velvetleaf as "infrequent" and gives six locations one could go to see this species in an area of about three counties. Velvetleaf was introduced from India to the southern colonies as a fiber crop in the Eighteenth Century. It subsequently spread to the Midwest with the westward migration of agriculture. During the late Twentieth Century it spread throughout the Northeast, probably in feed corn as dairy farms began importing more concentrates from the Midwest (Mt. Pleasant and Schlather 1994). Since the seeds readily pass through the bovine digestive tract, the farmers spread the weed on their fields with the cattle manure. As a result, about half the fields in New York now have velvetleaf. Since the seeds are very persistent in the soil, these fields will probably have velvetleaf for as long as they are farmed.

Conclusions

Agricultural weeds are not simply unwanted plants. Rather they are species with particular biological characteristics that set them apart from most other species, including most crops. These characteristics adapt them to the frequently disturbed conditions and high resource availability of cropped fields. These characteristics include:

- Resprouting from damaged roots and rhizomes of perennial weeds,
- Ability of seeds to recognize suitable conditions for germination, including proximity to the soil surface, the absence of competing plants, the presence of essential resources like nitrogen and water, and an appropriate season of the year for subsequent growth,
- Massive production of small seeds that persist for years to decades in the soil,
- Ability to rapidly take up and concentrate macronutrients.

Although these characteristics adapt weed species to prosper in cropped fields, they also provide opportunities for management.

- Breaking up perennial roots and rhizomes increases the number of shoots of wandering perennials, but each of the subsequent shoots is weaker and more easily managed by cultivation or competition. Removal of above ground shoots forces the perennial to move resources from the storage organ into new shoots, thereby decreasing its ability to survive over the long term.

- Understanding of the germination biology of annual weeds allows the farmer to trick the seeds into germinating at times when they are easily controlled, for example, by a short period of clean fallow or a smother crop. Rotation of crops with different seasonality presents some species with inappropriate conditions for germination each year, thereby allowing attrition by natural processes to decrease soil seed banks.

- Recognition of the seed production potential of weeds and how this varies with weed size makes the economics of preventing seed production more attractive.

- Finally, the great difference in size between weed seeds and crop seeds or transplants allows for in-row mechanical weeding of many crops, and is a fundamental reason organic mulches are effective for weed management.

Much remains to be discovered about the biology of weeds. Germination requirements have been fully analyzed for only a few species. More critically, effects of the soil environment on weed growth and competition with crops has been little studied. In some cases, slow releasing forms of nitrogen like compost and green manure appears to favor crops whereas chemical fertilizers appear to favor weeds, but the generality of this phenomenon has not been demonstrated. The role of micronutrients and ratios of macronutrients are widely believed among organic farmers to be important for both crop growth and weed competition, but these topics have received little systematic research, particularly in organic systems where effects are less likely to be masked by intensive chemical management of crops, weeds and soils. Hopefully, the recent growth in the organic sector will spur increased investigation of these topics.

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