Penn State **Extension**

START FARMING

Introduction to Organic Vegetable Production

APPRENTICE READER

In collaboration with Pennsylvania Collaborative Regional Alliance for Farmer Training (CRAFT) and the Seed Farm – Lehigh County's New Farmer Training Program and Agricultural Incubator.

PENNSTATE

Cooperative Extension
College of Agricultural Sciences

Dear apprentice farmers,

Welcome to the farming community. I hope you have a wonderful season. This is an exciting time to start farming. With five times more farmers over the age of 65 than under 35 we need new farmers like you. Local food is hot- the trend favoring local food and know your farmer is in your favor. We have come a long way since the word 'locavore' was invented in 2005 by Chef Jessica Prentice in San Francisco. Now everyone knows that local food means fresh, tasty, more sustainable and supporting local communities. They are asking for local food. Four out of five respondents to a 2006 national survey said they purchased fresh produce directly from growers either occasionally or always. These local saavy consumers are in your neighborhood. One in five US consumers live within a days drive of SE PA.

You have picked a wonderful place to learn to farm. In addition to a fabulous community of mentor farmers through the Collaborative Regional Alliance for Farmer Training (CRAFT) of which you are a part, the Pennsylvania Association for Sustainable Agriculture (PASA), the New Jersey Organic Farming Association (NOFA NJ), and Penn State Extension – Start Farming programs provide a wide assortment of workshops and resources in this area. Greener Partners has also generously donated time to organize CRAFT PA. The Seed Farm – Lehigh County's Agricultural Incubator and New Farmer Training project has helped create much of the material involved in this manual.

To a wonderful season - Good work, good food, good friends and sustaining our communities.

Sincerely,

Tianna DuPont
Sustainable Agriculture Educator
Penn State Extension

610-746-1970
tdupont@psu.edu
extension.psu.edu/start-farming
extension.psu.edu/vegetable-fruit

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I also want to recognize the UC Santa Cruz "Teaching Organic Farming and Gardening" manual and Vernon Grubinger's "Sustainable Vegetable Production from Start-Up to Market' that have been invaluable resources.

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Seed and Seedling Biology

As organic producers, we try to mimic nature in order to grow food with a minimum of external inputs. If we plan to mimic nature, we need to understand as much about the biology of plants and ecological systems as we can. The following introduction may be a review for some, but will hopefully give new producers an understanding of seed and seedling biology and a framework for analyzing cultural practices for producing healthy seedlings.

Choosing the right seed

Before exploring how to best grow your seeds and seedlings, start with the right seed. If you intend to run your operation as certified organic, you are required to use certified organic seed and seedlings with only a few exceptions. See the side bar on page 5 for details.

What do seeds need to germinate?

Viable seeds are living entities. They must contain living, healthy embryonic tissue in order to germinate. All fully developed seeds contain an embryo and, in most plant species a store of food reserves, wrapped in a seed coat. Seeds generally "wake-up" and germinate when soil moisture and temperature conditions are correct for them to grow [4]. Each seed type has individual needs. It is important to take a minute and read about its specific germination requirements.

Seeds need the right environment to germinate

Temperature, moisture, air and light conditions must be correct for seeds to germinate. All seeds have optimal temperature ranges for germination (see sidebar). The minimum temperature is the lowest temperature seeds can germinate effectively. The maximum is the highest temperatures seeds can germinate at. Anything above or below this temperature can damage seeds or make them go into dormancy. At optimal temperatures, germination is rapid and uniform.

Soil Temperature Conditions for Vegetable Crop Germination

	Min (°F)	Opti-mum Range (°F)	Optimum (°F)	Max (°F)
Beet	40	50-85	85	85
Cabbage	40	45-95	85	100
Cauliflower	40	45-85	80	100
Celery	40	60-70	70	85
Chard	40	50-85	85	95
Cucumber	60	60-95	95	105
Eggplant	60	75-90	85	95
Lettuce	35	40-80	75	85
Melons	60	75-95	90	100
Onion	35	50-95	75	95
Parsley	40	50-85	75	90
Pepper	60	65-95	85	95
Pumpkin	60	70-90	90	100
Spinach	35	45-75	70	85
Squash	60	70-95	95	100
Tomato	50	70-95	85	95

Soil temperatures should be taken by inserting a soil thermometer 3 to 4 inches deep into the soil surface and noting temperature.

Adapted from [3].

All seeds need correct moisture to initiate internal processes leading up to germination. In field soil this is generally about 50 -75% of field capacity. A fine textured seed bed and good seed to soil contact is necessary for optimal germination. Aeration in the soil media allows for good gas exchange between the germinating embryo and the soil. Seeds respire just like any other living organism. They need oxygen and produce carbon dioxide (CO_2). This carbon dioxide needs to be able to move away from the seed. If the soil or media is not well aerated due to over watering or compaction, the CO_2 will not dissipate and seeds can suffocate.

Not all seeds have the same light requirements. Most seeds germinate best under dark conditions, and might even be inhibited by light (e.g. *Phacelia*, Alliums). However, some species (e.g. Begonia, Primula, Coleus) need light to germinate [4]. Don't confuse seed light requirements with what seedlings need. All seedlings require sunlight. Seedlings will become leggy and fragile and not produce to their potential if they do not have sufficient light (see sidebar).

Seed Dormancy

Some viable seeds might not germinate. Many seeds have developed a dormancy (or sleep) period. Seed dormancy is a condition that prevents germinating even under optimal environmental conditions. Why would it benefit seeds to not all germinate when conditions are right? In nature, staggering germination keeps some seedlings safe from possible bursts of bad weather or herbivores that might eat them. Seeds of plants that grow best in the spring have self selected to germinate only after cold winter temperatures have passed.

For seeds to come out of dormancy, we have to break their physical or chemical dormancy factors. Seeds might have a hard or thick seed coat (physical dormancy). This can be broken by soaking or scarifying (scratching the surface) the seed. Other seeds have internal chemical or metabolic conditions that prevent germination (chemical dormancy). Factors affecting seed dormancy include the presence of certain plant hormones, notably abscisic acid, which inhibits germination, and gibberellin, which ends seed dormancy. To break chemical dormancy, you might have to leach the seed, use cold/moist stratification, or fire scarification. For example, the membrane within the seed coat of some seeds forms a barrier that is permeable to water but not to oxygen. Cold temperatures (50 F to 59 F) allow oxygen to get into the seed while warm temperatures prevent oxygen uptake. Cool temperatures also allow the seed to digest some of its food reserve giving it energy. For these seeds, putting them in the refrigerator for a specific period of time allows them to gain sufficient oxygen and energy to germinate [5].

Seedlings will become leggy and weak in low light situations.

To check if your seed is viable, do a germination test. Wrap seeds in a moist paper towel. Wait 5-10 days and count what percentage of seeds germinate.

If you save your seed from the year before, think about this. The life of a seed can be cut in half by an increase of just 1% in seed moisture or by an increase in storage temperature of just a few degrees. A simple rule of thumb is that the sum of the storage temp in F and percent relative humidity should not be greater than 100.

Steps of Seed Germination

Step 1: Imbibation. The seed rapidly takes up water and the seed coat swells and softens. Think of a pea seed that you have soaked. The outer seed coat becomes soft and wrinkly with water.

Step 2: Iterim or lag phase. During this phase the seed activates its internal physiology. Cells respire. It starts to make proteins and metabolize its stores of food [1].

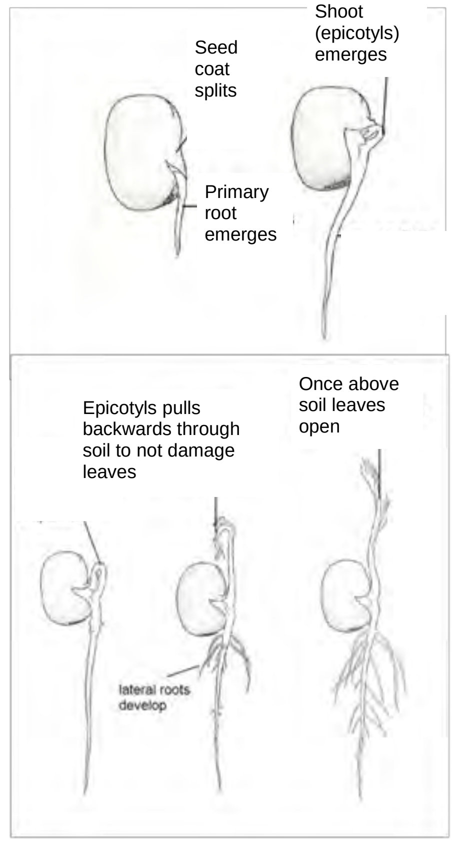
Step 3: Radicle and root emergence. The cells start to elongate and divide bringing the root and radicle out of the seed.

Early Seedling Development

Dicots (2 seed leaves). The primary root called the radicle is the first thing to emerge from the seed. The primary root anchors the plant to the ground and allows it to start absorbing water. After the root absorbs water the shoot emerges from the seed. In dicots, the shoot has three main parts: the cotyledons (seed leaves), the section of shoot below the cotyledons (hypocotyl), and the section of shoot above the cotyledons (epicotyl) [6]. The way the shoot emerges from soil or growing media follows two main patterns. In some plants, the section of the shoot below the cotyledons elongates and forms a hook pulling the cotyledons and the growing tip through the soil. Once it reaches the surface, it straightens and pulls the cotyledons and shoot tip of the growing seedlings into the air. For example, beans germinate this way. This is called epigeous germination. In other plants, only the section above the cotyledons expands leaving the cotyledons underground where they soon decompose. This is called hypogeous germination. Peas for example germinate this way [6].

Monocots (1 seed leaf). In monocot seeds, the primary root is protected by a sheath (coleorhiza), which pushes its way out of the seed first. Then the seedling leaves emerge covered in a protective sheath called coleoptiles [6].

Dicots and Monocots. After the shoot emerges, the seedling grows slowly while the storage tissue of the seed diminishes. Soon, the plant develops a branched root system or tap root. Then, true leaves that look like the leaves of the mature plant appear. These leaves, unlike cotyledons, photosynthesize light into energy allowing the plant to grow and develop.



Broad bean germination
From Mackean DG & Mackean I 2010 [1].

Heat stress can cause severe damage to tiny seedlings. These recently emerged broccoli seedlings were exposed to temperatures of 118º F.

Photo S. T. DuPont, PSU.

Managing for Optimal Germination and Seedling Development

Optimizing Germination. We know that seeds need optimal amounts of water, oxygen, temperature and light to germinate. If we don't create the most optimal environment possible, then plants tend to germinate slowly and unevenly. Generally greenhouse space is limited, so we want plants to germinate as quickly as possible. Uneven germination can also cause problems. If you have ever had to transplant out a flat of seedlings where half are ready to plant and the other half are two small with root balls that don't slide easily out of their cells, you will understand why.

One common option to achieve optimal germination temperature in growing media are germination mats. These mats allow you to set the temperature according to seed requirements. For example, peppers will germinate in 8 days at 86 F, but take more than 13 days to germinate at 58 F [7].

Make sure you maintain optimal temperatures for your crop (see sidebar pg 1). It is also critical to promote air circulation to mitigate fungal pathogens such as those causing damping off.

Seedling Development. The optimal temperature for seedlings may be different than that for seeds (see sidebar). Remember optimal temperature will stimulate optimal growth. To control plant height you can control temperatures. Cooler temperatures generally slow down growth, and warmer ones speed up growth.

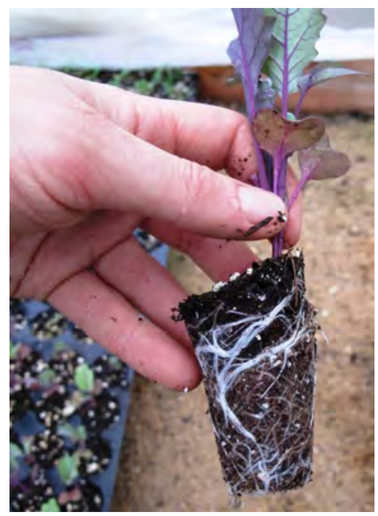
It is still critical to maintain good air circulation and sufficient moisture. Generally, watering should be deeper to accommodate developing roots systems. You may need to use different wand or hose heads to water seeds and seedlings because each use different amounts of water. Remember to carefully monitor and water the plants at the edges of flats. They dry out faster than those in the middle. However, over watering can increase the probability of plants developing damping off.

Seeding Maturation and Hardening Off. This final step before seedlings are planted in the field gradually exposes them to the conditions they will have in the field. This process stimulates the plants to accumulate carbohydrate and nutrient reserves and strong cell walls by exposing the plants to day and

Temperature and Time Required for Growing Field Transplants

	Day (°F)	Night (°F)	Time (weeks)
Broccoli	60-70	50-60	5-7
Cabbage	60-70	50-60	5-7
Cauliflower	60-70	50-60	5-7
Celery	65-75	60-65	10-12
Cucumber	70-75	60-65	3-4
Eggplant	70-80	65-70	6-8
Lettuce	55-65	50-55	5-7
Melons	70-80	65-70	3-4
Onion	60-65	55-60	10-12
Pepper	65-75	60-65	6-8
Squash	70-75	60-65	3-4
Tomato	65-75	60-65	5-7

From *Knott's Handbook for Vegetable Growers* [2].



Shallow watering will leave most of the roots dry and stress the plant. See the lighter colored potting mix in the bottom half of the root ball right.

Photo S.T. DuPont, PSU.

Poor onion germination due to over watering, cold soils and damping off complex. Photo S.T. DuPont, PSU.

night temperature fluctuations, increased air movement and wind, reduced watering, and full light. Hardening-off transplants is important, especially if they are to be planted under stressful, early season conditions. Most transplants may be hardened-off by reducing temperature in the greenhouse through ventilation. Reduced watering will also provide some hardening effect. Do not let plants wilt excessively. Do not harden-off transplants by reducing fertilizer application, as this often results in stunted plants which do not establish well in the field. Some growers will put plants outside for 5 to 7 days prior to planting. This allows the plant to become acclimated to outside conditions while still in the flat. Plants hardened-off in this manner often have improved field performance as compared to those planted directly from the greenhouse [8].

Organic Seed Sources

Listed below are a number of sources for organic seed provided by Pennsylvania Certified Organic [11]. A list is also maintained by the Organic Material Review Institute www.omri.org. For a more complete listing including forage, field crop, cover crop seed and transplants please go to pco.org and

ABUNDANT LIFE SEEDS
P.O. Box 157
Saginaw, OR 97472
541-767-9606
www.abundantlifeseeds.com
info@abundantlifeseeds.com
100% organic. All open pollinated.
Vegetable, flower & herb seed,
garlic & potatoes.

THE COOK'S GARDEN
P.O. Box C5030
Warminster, PA 18974
800-457-9703
www.cooksgarden.comcooksgarden@earthlink.net
Organic vegetables, beans, flowers, & herbs.

ENVIRONMENTAL SEED PRODUCERS
P.O. Box 947
Albany, OR 97321-0354
541-928-5868
www.espseeds.com
Organic vegetables, herbs & flowers.

ENVIRONMENTAL SEED PRODUCERS
P.O. Box 947
Albany, OR 97321-0354
541-928-5868
www.espseeds.com
Organic vegetables, herb & flowers.

FILAREE FARM
182 Conconully Hwy.
Okanogan, WA 98840
509-422-6940
www.filareefarm.com
Extensive collection of organic garlic varieties.

FEDCO SEEDS
PO Box 520
Waterville, ME 04903
207-873-7333
www.fedcoseeds.com
Organic vegetables, flowers &

Organic Requirements for Seeds, Planting Stock and Seedlings

The National Organic Standards require that the producer use organically grown seeds, annual seedlings and planting stock, except that non-organically produced, untreated seeds and planting stock may be used to produce an organic crop when an equivalent organically produced variety is not commercially available.

There is **no allowance** for seed treated with prohibited materials! Captan, Thimet and similar chemical fungicides are NOT on the National List and are not permitted. PLEASE TAKE THIS SERIOUSLY. If your seed is covered in a pink or orange powder, it is probably prohibited! We may not be able to certify your crop if you use seed treated with prohibited materials.

Seeds used for edible sprout production **must** be organic, no exceptions!

COMMERCIAL AVAILABILITY

The first step is to determine if an equivalent organically produced variety is available. By equivalent variety, look for comparable growing habits, days to maturity, insect and disease resistance, flavor and other important qualities. If a suitable equivalent variety is not available,

Cont. pg. 6

search for Organic Seed Suppliers.

FRED C. GLOECKNER & CO. INC.
600 Mamaroneck Avenue
Harrison, NY 10528-1631
800-345-3787
914-698-2857 (fax)
www.fredgloeckner.com
Organic vegetable, herb, & flower seeds.

GARDENS ALIVE!
500 Schenley Place
Lawrenceburg, IN 47025
513-354-1482
www.gardensalive.com
Organic garden & sprout seeds, plus insect & disease control and soil care products.

HARRIS SEEDS
355 Paul Rd. PO Box 24966
Rochester, NY 14624-0966
800-544-7938
www.harrisseeds.com
Some organic vegetables & herbs.

HIGH MOWING ORGANIC SEEDS
76 Quarry Road
Wolcott, VT 05680
802-472-6174
www.highmowingseeds.com
We offer high quality organic seed for over 500 varieties of heirloom, open-pollinated and hybrid vegetables, flowers, herbs, potatoes, garlic, and cover crops.

JOHNNY'S SELECTED SEEDS
955 Benton Avenue
Winslow, ME 04901
877-JOHNNYS
(877-564-6697)
www.johnnyseeds.com
Organic vegetables, flowers & herbs.

THE MAINE POTATO LADY
PO Box 65
Guilford, ME 04443
207-343-2270
www.mainepotatolady.com
Organic seed potatoes, shallots, onion sets, garlic, & cover crops, plus fertilizer, soil & seed inoculants.

ROHRER SEEDS
PO Box 250
Smoketown, PA 17576
717-299-2571
www.rohrerseeds.com
Organic vegetable seeds.

SEEDS OF CHANGE
3209 Richards Lane
Santa Fe, NM 87507
888-762-7333
www.seedsofchange.com
Organic flowers, herbs, vegetables & cover crops and strawberry plants.

SEED SAVERS EXCHANGE
3094 North Winn Road
Decorah, IA 52101
563-382-5990
www.seedsavers.org
Some organic vegetables, garlic, herbs, potatoes & heirloom varieties.

SEEDWAY, LLC
99 Industrial Road
Elizabethtown, PA 17022
800-952-7333
717-367-1075
www.seedway.com
Some organic vegetables & herbs.

SNOW SEED ORGANIC
21855 Rosehart Way
Salinas, CA 93908
831-758-9869
www.snowseedco.com
Many organic vegetables including lettuces.

SOUTHERN EXPOSURE SEED EXCHANGE
PO Box 460
Mineral VA 23117
540-894-9480
www.southernexposure.com
400+ varieties of Certified organic heirloom & open pollinated vegetable, herb and flower seeds as well as garlic and perennial onion bulbs.

organically, document where you tried to look for organic seed, as that is important for your certification records. Once you have found a source for a specific equivalent organic seed, the next step in determining commercial availability is to see if it is the appropriate:

• Form – such as sized, graded, pelleted, hot water treated.
• Quality - you may want to try a small quantity the first year to make sure it does well under your particular conditions. If the only seed available organically is of inferior quality then it may be acceptable to buy non-organic
• Quantity – example: if you want to plant 1 acre of pumpkins and the only organic seed available is in 1 oz packets, then it may be acceptable to buy non-organic

Documentation and Good Faith Efforts

Prior approval by PCO for using non-organic seeds/planting stock is not required. Compliance is reviewed in the context of the organic system plan, which is verified during the annual inspection. A pattern of inadequate documentation and lack of good faith effort to obtain organically grown seeds and planting stock may be considered non-compliance and might result in PCO requiring prior approval regarding commercial availability issues in future planting cycles. Documenting your good faith efforts to find suitable organic seeds/planting stock is crucial.

PCO Seed Guidance Sheet 1-4-08 [9].

TERRITORIAL SEED COMPANY
P.O. Box 158
Cottage Grove, OR 97424
800-626-0866
www.territorialseed.com
Organic flowers, herbs, vegetables, garlic, & cover crop seeds, plus OMRI listed fertilizers & soil amendments.

VITALIS ORGANIC SEEDS
7 Harris Place
Salinas, CA 93901
831-262-7635
www.vitalisorganic.com
Organic veg and herb seeds, with emphasis on lettuce, spinach, tomato, pepper, cucumber, squash,& melons.

WOOD PRAIRIE FARM
49 Kinney Road
Bridgewater, ME 04735
800-829-9765
www.woodprairie.com
Organic garden seed, seed potatoes, and cover crop seed.

1. Mackean, D.G., *Seed Structure*, in *Resources for Biology Teaching*: http://www.biology-resources.com/plants-seeds.html.
2. D.N., M. and G.J. Hochmuth, *Knott's Handbook for Vegetable Growers*. Vol. 5. 2007, Hoboken, NJ: John Wiley and Sons, Inc.
3. Kemble, J. and M. Musgrove, *Soil Temperature Conditions for Vegetable Seed Germination.* Alabama Cooperative Extension ANR-1061, 2006.
4. Miles, A. and M. Brown, *Teaching Organic Farming and Gardening: Resources for Instructors*. 2007, Santa Cruz, CA: University of California Farm and Garden.
5. *Physiological Dormancy*, in *www.seedimages.com/dormancy/physiological-dormancy.html*. 2009, Colorado Seed Laboratory.
6. Raven, P.H., F.E. Ray, and S.E. Eichhorn, *Biology of Plants, 7th Edition*. 2005, New York: W.H. Freeman and Company Publishers.
7. Club, P.H.S.S., *Seed Germination and Temperature.* http://www.paseedsavers.org/Seed_germination_and_termperature.htm.
8. Garton, R.W., P.H. Sikkema, and E.J. Tomecek, *Plug Transplants for Processing Tomatoes: Production, Handling and Stand Establishment* Ministry of Agriculture and Rural Affairs Ontario Canada, 1997.
9. Pennsylvania Certified Organic. *Seed Guidance Sheet.* Spring Mills, PA. www.paorganic.org.
10. Pennsylvania Certified Organic. *2011 Organic Seed Suppliers.* Spring Mills, PA. www.paorganic.org.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension. Reviewed by Elsa Sanchez, PSU Horticultural Systems Management and Debra Brubaker, Pennsylvania Certified Organic. *Last updated May 2011.*

Soil Media and Plant Propagation

Potting mixes should support developing seedlings. Most potting mixes are soil-less to avoid soil borne diseases and promote good drainage. A mix of peat moss, vermiculite or perlite and compost or organic fertilizers can provide a suitable environment with sufficient water holding capacity, nutrient content and aeration for plant growth and development. However, because organic nutrients are supplied slowly over time it can be difficult to meet seedling nutrient needs. The following outlines basic recipes for potting media and research on organic transplant production.

Commercial mixes

There are a number of commercial mixes available for organic growers. Make sure you know what the ingredients are in a commercial mix and check to see if it is Organic Materials Review Institute (OMRI) listed. It should state "OMRI listed" on the packaging. If not, you can check the OMRI website (omri.org) to see if it is listed. It is always best to call your certifier to ensure that using the mix will not compromise your certification. Many commercial mixes contain wetting agents to facilitate water absorption by peat moss. Synthetic wetting agents are not allowed under organic production standards [1].

Depending on the certifier, a producer can also request that the certifier review a specific product/media. OMRI has not reviewed all products. For example Pennsylvania Certified Organic (PCO) has an internal Materials Review and publishes a list of materials that they have reviewed and approved. Members of PCO can request a review of any product free of charge). It is very important that any material input have been pre-approved by a certifier to prevent delays in your certification.

Test your mix before you use it.

If you are unfamiliar with your mix or have received a new batch it is a good idea to do a greenhouse soil test [2]. Mixes made with compost can be high in salts which can inhibit

Potting Mix Bioassay to avoid the effects of high salt levels or herbicide residue.

Steps:

1)Fill a flat with potting mix.
2) Count out 25 seeds of cress, lettuce or other fast germinating crop.
3)Seed flat.
4)Wait 5-7 days.
5)Count number of seedlings.

If less than the legal germination rate (for lettuce 80%) you may want to test your media for salts.

Potting mix on the right was high in salts.

germination. To test your mix you can send it to a reputable lab for greenhouse testing. Remember, *this is different* from a soil test. For example, Penn State's Ag Analytical Lab has a "Greenhouse Soil-less Media" test that will analyze your media's pH, soluble salt (electrical conductivity) and nutrient content. Media sent in as a *soil* sample is tested differently and results will not make sense.

Premium potting mixes tested with the saturated paste method recommended for greenhouse media will have a pH between 5.5 and 6.5, soluble salts between 1.5 and 3 mmhos/cm, nitrate nitrogen (NO3) levels between 75 and 150 mg/L, phosphorus (P) levels between 5 and 20 mg/L, potassium (K) between 150 and 300 mg/L, calcium between 100 and 200 mg/L and magnesium between 50 and 100 mg/L, with sodium contents falling below 160 mg/L [9-10].

Consider pre-testing your potting mix by doing your own greenhouse bioassay. To do a bioassay, grow cress, oats, beans, lettuce or another fast growing crop with a high germination rate in your soil mix. If there is a problem with the mix, you will see it in reduced germination or poor seedling growth (See "Potting Mix Bioassay" sidebar for details). You may also compare your new mix to a mix that you are satisfied with.

Recently, hand held EC (electrical conductivity) meters have become more popular and available at reasonable prices. See reference [3] for more information on how to test for salts using an EC meter.

Making your Own Mix

Even when making your own potting media, it is still important to ensure the that individual components of the media are specifically approved for certified organic production. (See sidebar for specifications for compost.) If you are purchasing compost to add to your homemade potting mix, most certifiers will require that this compost is reviewed (PCO requires an ingredient list from the source and a compost log in cases when the raw manure restriction is applicable). Fertility amendments, peat, coir and other components must also be approved. Check for the OMRI label or talk with your certifier. Please see reference [10] for details.

When you first start making your own potting mix, it's a good idea to try several different recipes that have worked for other growers, and compare how they do on your own farm. A list of common potting mix recipes is at the end of this document.

Many organic potting mixes contain compost, which can provide many benefits. Compost adds organic matter to the mix and supports diverse microbial populations that can suppress

Organic Standards for Compost

The National Organic Standard is very explicit about compost preparation. Compost piles must maintain a temperature between 131 and 170 degrees Fahrenheit for at least 3 days in a static or enclosed vessel system, or at least 15 days in a windrow system, with at least 5 turnings. Unless these criteria are met, the resulting product is not — in the eyes of the National Organic Program — considered compost. Rather, it is simply a pile of raw materials. If one of those raw materials is manure, it can make a big difference in how it may be used in crop production. Raw livestock manure can carry pathogens that pose a danger to human health. According to the NOP's rules, raw manure: can be applied at will to crops not intended for human consumption; cannot be applied to a crop within 120 days of harvest if the edible portion has direct soil contact; cannot be applied to a crop within 90 days of harvest when the edible portions have contact with the soil.

soil born disease causing organisms [4]. Microbes break down organic material, releasing plant-available nutrients that are slowly available for your seedlings.

However, growers have increasingly reported problems with compost based mixes. This may be because they rely on microbial release of nutrients which may occur too slowly to meet plant needs.

In a recent study, Rangarajan et al. compared 20 organic potting mixes [5]. They found that transplants grown in potting mixes that contained blood meal or alfalfa meal in addition to compost were significantly larger. This was probably in response to ammonium N levels being 2-3 times higher than in mixes without either compost or bloodmeal amendments [5]. It may be a good idea to use a mix with a more readily available N form like bloodmeal in addition to compost. Bloodmeal seems to stimulate microbes and increase nutrient availability from compost.

If you use compost, make sure you are using high quality compost at the right stage of maturity. Unfinished compost may release volatile organic acids that can negatively affect seedling growth and development [6]. One classic method of evaluating compost readiness is by smell. Finished compost has a sweet smell. Anaerobic, sour or putrid smells are suspicious. If your nose detects an off smell, turn the pile and let it heat again before considering using it in a mix [4].

Problems with compost-based mixes often occur during early season transplant production. This may be because the mix is too cold, especially overnight when greenhouse temperatures drop. Compost supports an active biological system. Microbe activity is linked to temperature and will not release nutrients if temperatures are cold and do not support their activity. To alleviate this problem many growers provide bottom heat to their transplants. See *Farm Profiles: Red Cat Farm* for an example.

Supplemental Fertility

If, after all possible precautions, your transplants are stressed due nutrient deficient media, you may need to use supplemental fertilizers such as fish emulsion. Organic sources of supplemental fertilizer include fish emulsion, soluble fish powder, kelp extracts, worm casting or compost tea or other OMRI approved products. See *Using Organic Nutrient Sources* reference [7]. These fertilizers can be applied to the soil by fertigation or foliar spray. Be careful with supplemental fertility. If you produce transplants in an area that is later used for in ground production, leached fish emulsion or other products can build up soil nutrients to levels exceeding crop needs.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension. Reviewed by Elsa Sanchez, Penn State Horticultural Systems Management; Debra Brubaker, Pennsylvania Certified Organic.

Seedling mixes for starting transplants

The following list was compiled by M. Wander in *Organic Potting Mix Basics [1]*.

Seed mix (Biernbaum, 2001)

- 2 parts screened compost
- 4 parts sphagnum peat
- 1 part perlite
- 1 part vermiculite
- Lime as needed to adjust pH to 6

Seed mix - standard soil-less (Biernbaum, 2001)

- 50–75% sphagnum peat
- 25–50% vermiculite
- 5 lbs of ground or superfine dolomitic lime per cubic yard of mix
- Blood meal, rock phosphate, and greensand at 5 to 10 lbs per cubic yard

Soilless potting mix (used by Windsor Organic Research on Transition project, E. Zaborski)

- 1 part compost
- 1 part vermiculite
- 1 part peat moss

Screened with ¼ inch screen to mix together. Per 1 gallon mix add:

- 0.6 oz blood meal (17.01 grams)
- 0.4 oz clay phosphate (11.34 grams)
- 0.4 oz greensand (11.34 grams)

Organic potting mix (credited to Eliot Coleman in Kuepper, 2004).

- 1 part sphagnum peat
- 1 part peat humus (short fiber)
- 1 part compost
- 1 part sharp sand (builder's)

to every 80 quarts of this add:

- 1 cup greensand
- 1 cup colloidal phosphate
- 1½–2 cups crabmeal or blood meal
- ½ cup lime

Soil block mix (Kuepper, 2004; adapted from Coleman, 1995)

- 3 buckets (standard 10-qt. bucket) brown peat
- ½ cup lime (mix well)
- 2 buckets coarse sand or perlite
- 3 cups base fertilizer (blood meal, colloidal phosphate, and greensand mixed together in equal parts)
- 1 bucket soil
- 2 buckets compost

Seedling mix for soil blocks or seedling flats (from John Greenier of Stoughton, WI in Kuepper, 2004)

- 2 3-gal. buckets Sphagnum peat moss
- ¼ cup lime
- 1½ cups fertility mix (below)
- 1½ buckets vermiculite
- 1½ buckets compost

Fertility mix:

- 2 cups colloidal (rock) phosphate
- 2 cups greensand
- 2 cups blood meal
- ½ cup bone meal
- ¼ cup kelp meal

Directions for mixing:

1. Add peat to cement mixer or mixing barrel.
2. Spread the lime and fertility mix over the peat.
3. Mix these ingredients thoroughly.
4. Add the compost and vermiculite and mix well again. 5. When done, examine the distribution of vermiculite to ensure that it has been mixed in evenly.

Note that all bulk ingredients should be screened through 1/4 inch hardware cloth. Well matured, manure-based compost should be used (avoid poultry manure and wood-chip bedding).

1. Wander, M. Organic Potting Mix Basics. http://www.extension.org/article/20982 2009.
2. Grubinger, V.P., Potting Mixes for Organic Growers. University of Vermont Extension, 2007.
3. Sanchez, E., Saline Soils and Plant Growth. 2010, http://extension.psu.edu/vegetable-fruit/fact-sheets: Penn State Extension.
4. Klein, J. and K. Hammer, Compost-based potting mixes require different management for transplants. Growing for Market, 2006.
5. Leonard, B. and A. Rangarajan, Organic Transplant Media and Tomato Performance 2007 C.U. Dept. of Horticulture, Ithaca, NY 14853 Editor. 2007.
6. Grubinger, V.P., Sustainable Vegetable Production from Start Up to Market. 1999, Ithica, New York: National Resource Agricultural Engineering Service Cooperative Extension.
7. Sanchez, E. and T.L. Richard, Using Organic Nutrient Sources. 2009, The Pennsylvania State University: University Park, PA.
8. Pennsylvania Certified Organic. Compost Manure and Tea Guidance Cert A08. www.pco.org, 2010.
9. Warncke, D. 1995. Recommended Test Procedures for Greenhouse Growth Media. p. 76-82. In J. Thomas Sims and A. Wolf (eds.) Recommended Soil Testing Procedures for the Northeastern United States. Northeast Regional Bulletin #493. Agricultural Experiment Station, University of Delaware, Newark, DE.

Crop Planning

Goals in Planning – Time management is my major reason for doing extensive crop planning. The more I can organize during the winter, the smoother things go during the season. Another important piece is good data collection. We all want to continually improve our production. But if we don't know what we did last year, it is hard to access what worked and what did not work. Of course there are plenty of farmers who are able to hold the important information in their heads. But when you are getting started it is often helpful to have a few things to go by namely: **the seed order, bed preparation schedule, greenhouse seeding sheet, direct seeding and transplanting schedules, a harvest record sheet and a detailed map.**

Why Spreadsheets –"I want to be a farmer because I don't like to sit in front of a computer," you say. Well, everything we are going to talk about today can be done with a piece (or 10) of graph paper and a calculator. John Jeavons book "How to Grow More Vegetables," [1] does a nice job of putting a lot of relevant information on a few pieces of paper in graph form. This is a handy reference. But what it does not do is allow you to reformat the information according to what data you really want to see, or easily update it year to year. Josh Volk frequent contributor to "Growing for Market" says if you were going to do something similar on paper you would put each row of the spreadsheet on an index card. There would be an index card with each planting on it and all the corresponding yield, planting, seeding and ordering information. You could then arrange the index cards by planting date, by crop, by variety or by seed company order form. But it would take some time considering that you would have hundreds of index cards [2]. With the computer you can just sort the rows depending on what you are interested in looking at.

The Process – The process outlined here is adapted from a process shared by Josh Volk from Slow Hand Farm, frequent contributor to Growing for Market. When one of the farmers I work with asked what he does differently than they do, Josh responded, "Probably not much." This outline just gives those of us not familiar with forming spreadsheets and crop plans some handy steps and formats to use. The key here is we will form something Josh calls a "crop master" or master spreadsheet with all the information about our crops. From there we can create the seeding, transplanting and greenhouse charts and easily update them when we get new information.

Step 1 - Collecting the Data – What data is available and where to find it will of course depend a little bit on where you are and what sort of operation you have. But there are a few likely places to look. The Cooperative Extension offices have a lot of information about growing crops in their production guides, but to get more specific information one of the best places to look is often the seed catalogs. They usually put very specific information about everything from the number of seeds per ounce to plant spacing. Knott's Handbook for Vegetable Growers [3] is a good all around source for vegetable information such as germination temperatures, plant spacing, scheduling successive plantings and more. I like John Jeavons' book as well, though his plant spacing are designed for intensive raised bed systems that don't work in my field. Everyone's brain works differently which makes it hard for us to use each other's spreadsheets. I have included a sample here and there is another nice example available online from Roxbury

Farm. For me it makes the most sense to gather all the data in the first part of my spreadsheet. Then I can work to process it into the other information I need. I love sitting down with my seed catalogs and thumbing through them to decide what I want to grow this year. The first 21 columns in my spreadsheet are all the data I think I might want about each crop. Everything from crop and variety names to plant spacing, seeds per ounce, and ordering information. This may seem a little overwhelming at first. But the nice thing is you won't ever have to do as much work again. You will probably grow many of the same crops and varieties next year and you will have all the data right there.

Step 2 – Calculating Yield Needed – Whether you plan to grow for a market or for a CSA it is important to try to grow an appropriate amount for that market outlet. In the case of a CSA this can be more than a little nerve wracking because you have pretty well guaranteed a certain number of people produce every week and they are hoping they don't just get swiss chard every week. Yield calculations are never going to be perfect. But every year you will be able to get closer if you have a starting point. There are a few ways to do this but this is a feasible option.

For a CSA the data you will need is the # of CSA shares, the quantity you will give each shareholder in a given week, the unit, the number of weeks you expect a specific crop succession to produce, the # of varieties if you plan to plant more than one thing and give people a mix of say tomatoes, and whether the crop received multiple harvests or not..

Crop yield per planting you need = (# CSA shares) x (quantity/ share) x number of weeks

Step 3 – Bed/Row Feet per Planting – Next we want to know how much to grow to get that yield. I calculate this in bed feet. But if you are not in a bed system it works the same to calculate in row feet.

a. **Row feet per planting** = target crop yield ÷ crop yield per 100 ft row ÷ 100 ft
b. **Bed feet per planting** = row feet/planting ÷ # rows/bed

Step 4 & 5 – Timing Direct Seeding & Transplanting – To figure out when to plant each of these crops I work backwards from the target date I want to harvest. It may make more sense to you to work forward from the target seeding/transplanting dates to find the harvest date. If you work back from the target harvest date you will probably have to adjust for what is reasonable in your area in terms of frost free dates etc.

a. **Seeding date** = target harvest date – days to maturity
b. **Transplant date** = seeding date + days to transplant

Step 6 – Harvest Dates – You will need columns for seeding/transplanting date, days to maturity, weeks to maturity, and weeks of production.

a. Estimated 1st harvest date = seeding/transplanting date + days to maturity
b. Estimated last harvest date = 1st harvest date + weeks of production x 7

Crop Planning

Step 7 – Additional Transplanting Information – It is nice to gather here the information you will need when you are in the greenhouse – ie how many plants, the tray size and number of plants.

Step 8 – Seed Ordering Information – For this section you will probably want to make columns for the company, the number of seeds, the oz you need, seeds/ oz, minimum germination, cost and unit code.

Step 9 – Field Prep/ Cultivation - Field prep timing always depends on the weather, but it is nice to have target dates set for when you will want to do your field work. This is especially important when you have a cover crop to work in. Based on your experience of how long it takes for that cover crop to break down after you plow it in and if you plan to make beds you may want to have columns for 1st tillage, 2nd tillage, bed preparation, 1st cultivation and 2nd cultivation. I find it really important to have those 1st and 2nd cultivation dates on my calendar. With a hundred plantings to manage it is easy for me to forget to do that first cultivation when the weeds are tiny and then they get out of control.

Creating To Do Lists from the Plans – Now comes the fun part. It almost feels like magic. Once you have the data together you can easily pull from that data onto other spreadsheets to make to do lists. It is good to also add extra blank columns next to the tasks to record when things were actually done. It is good to make sure the sheet can be printed out on a single sheet of letter sized paper. That way you can keep a copy of everything handy in the greenhouse where it is easy to reach and volunteers or employees know where to find it. For example when a planting crew goes to the field they will have a clipboard that has the crop, variety, how many trays, the spacing and any other notes. These sheets can be sorted by date and field so all the plantings for that week are grouped together and all the plantings for a field are next to each other. That saves a lot of running back and forth to the greenhouse. The blank spaces make it easy for a crew to keep records and you to be able to understand them later.

a. Open a new worksheet
b. Name the worksheet
c. Fill in the column names for the information you want for the sheet – ie for the greenhouse seeding chart: crop, variety, seeding date, days in greenhouse, traysize, trays.
d. Create a sample formula line. This line will correspond with the cell above your data in the master sheet. You will not want to touch this line when you reformat reorder your data. For example to capture crop press = then go to the master sheet and click the box at the top of the crop line. Press enter.
e. Drag down these formulas. Now you have all the data from the master sheet for these relevant topics.

f. Reorder the data. You can reorder the data here by date or crop or field according to what is most helpful.

Again which sheets you choose to make is up to you, but these are a few common ones:

a. Greenhouse seeding chart
b. Direct Seeding Chart
c. Transplanting Chart
d. Field Prep/ Cultivation
e. Seed Order

Creating the Map – This is the one piece that is very difficult to link directly to your crop master. You pretty much need to work back and forth from your planting schedule to figure out where everything will go in the field. There are just too many factors for excel to take into consideration – from example, field A is wet, crops B and C should be close together, last year crop C was in bed 14.

One tip, instead of creating your map in space it can be helpful to think about it in time. When I have just a map of the field it is hard to know when a planting is supposed to come out and another one go in. This can be especially important when you want to fit in as many cover crops as possible.

Additional Tips for Using Excel – The following is a cheat sheet of spreadsheet features that Josh Volk commonly uses when he works with spreadsheets. It is important to keep in mind that these will work just fine in open office as well as excel.

Cell Address - the column letter followed by the row number (e.g. F35)

relative cell address - when you put a cell address in a formula it defaults to a relative cell address, meaning relative to the cell the formula is in. The cell address in the formula will change if you move the formula to another cell.

absolute cell address - you can make the column, or row, or both absolute (meaning they won't change if you move the formula to another cell). This is done by putting a $ in front of the letter, or number, or both (e.g. $F35, F$35, or F35 - meaning three different things)

Referencing - this lets you reference cells in other sheets, even other workbooks. This works just like other cell addresses. Be aware that if you move cells in the referenced sheet (by sorting or any other method) the cell will still be referenced but the information that was in it will not.

Formulas I use in crop planning
=+-/*() - pay attention to where your parenthesis are in the formula, it makes a big difference sometimes.

+- - adding or subtracting a number to a date is equivalent to adding or subtracting days. Very useful.

sum() - this adds up all of the cells in a range. Ranges of cells start with the top left cell address, are separated by a colon (or sometimes double periods), and end with the bottom right cell address (e.g. A1:C55, or A1..C55)

count() - This counts the number of cells in a range that have a number in them

countA() - This counts the number of cells in a range that have anything in them

If() - I used to use more if statements but they take up a lot of space and aren't really so useful in the end. Basically they will do one thing if a cell matches the criteria you're looking for, or something else if it doesn't.

Nesting formulas - I use a lot of formulas inside of formulas. You can nest a lot of formulas but usually it's easier to use multiple steps, showing each intermediate step in another column. This is much easier to edit in the future and to understand when you forget how the formula works.

1. Jeavons, J., *How to Grow More Vegetables: Than You Ever Thought Possible on Less Land Than You Can Imagine*.
2. Volk, J., *Tips of Using Spreadsheets for Crop Planning*, in *Growing for Market*. 2010, Fairplains Publications Inc.
3. D.N., M. and G.J. Hochmuth, *Knott's Handbook for Vegetable Growers*. Vol. 5. 2007, Hoboken, NJ: John Wiley and Sons, Inc.

Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, Northampton and Lehigh County, tdupont@psu.edu based on a presentation by Josh Volk, Slow Hand Farm, Portland Oregon.

Shooting Star Farms, Easton, PA   Transplants & Greenhouse Management

I run a small 15 member CSA in Easton, PA. The market garden covers 1/2 acre of the 2 acre rented space. The garden provides me with a place to experiment and learn as well as a chance to grow healthy vegetables for my neighbors. The techniques used follow certified organic standards and I plan to transition the land next year.

Seed Selection

I buy seeds from High Mowing Organic Seeds in Vermont, Johnny's selected seeds, and Seeds of Change. I try to pick as many disease resistant varieties as I can. I also buy some pelleted seed for tiny seed or things that I will be using the push seeder for.

Propagation Facility

I built a small plastic covered tunnel for propagation and early planting. It is 12 x 20' made with a metal frame and covered in greenhouse plastic. Rather than heat the entire tunnel we made two hot beds. One hot bed (front) is heated by an electric cable run through sand. The sand distributes the heat and gives the transplants the bottom heat that they like. When covered with plastic at night to retain the heat the hot bed does not get below 40 F even when the outside temp is down to 20 F. The other hot bed is heated by composting horse manure and bedding. While it composts it lets off heat and keeps the transplants warm. This system is a little bit more touchy. I have to keep adjusting the moisture and occasionally stirring it to keep it warm.

Propagation Trays

50 count deep trays

I use a variety of different trays. I start a lot of the brassicas, tomatoes and other easy to pick out plants in 1020s (flat closed bottom trays). This year I tried a new type of channel tray that keeps varieties organized and helps me keep things labeled. I tend to use 72s to save greenhouse space both for the transplants that I pick out and things like spinach that I will not move again until they are planted out. I ordered my propagation flats from Griffin this year, but I have ordered from Nolts out of Lancaster in the past and they are a bit cheaper for a harder plastic tray. I did try the deep 50s last year and I am not sure that it is worth the extra potting mix.

Sanitation

All used trays are sterilized in a 5% bleach solution for 30 minutes at the beginning of the season to minimize problems with damping off and other soil diseases.

Seeding and Picking Out

Channel Trays

For the small number of trays that I do, I just seed by hand. I find a chopstick helps me make holes for the transplants when I am pricking out small plants. For larger transplants, I start with just a small amount of soil mix in the bottom of the tray and then pack around the plants after each row. It is helpful of to think about minimizing movements instead of trying to seed faster.

Greenhouse irrigation

The greenhouse transplants are irrigated with well water applied with a wand sprinkler from a hose.

Planning

I use excel spreadsheets to plan my seeding and transplanting schedule. I started with a set of spreadsheets put together by Joel Gruver at NC State that I have adjusted. Now they help me calculate how much to plant as well as when to plant for successions throughout the season. I find it helpful to print my plot plan, seeding schedule, and a seeding/ transplant calendar and keep it all in a notebook in my greenhouse. The sheets are all in plastic covered sheets to keep water and dirt from ruining them.

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, 2010.

Eckerton Hill Farm, Lobachsville, PA Transplant Production

I visited Eckerton Hill Farm on April 1st 2010 and the greenhouse was already overflowing with transplants and scrumptious greens. Tim Stark, the farm owner was gracious enough to show me his greenhouse and transplant system before he headed into New York for deliveries including 52 lbs of baby radishes for his restaurant customers.

At Eckerton Hill Farm Tim and his crew have been growing a wide variety of vegetables with an emphasis on heirlooms since 1995. This includes over 100 varieties of tomatoes and 40-60 varieties of chili peppers every year. Until recently all growing took place on leased land and was directly marketed to New York's Union Square Greenmarket. 2009 was a milestone year for Tim with the purchase of the historic Angstadt farm, a beautiful 57 acre farm sitting atop the Oley valley in Lobachsville, PA.

Seed Selection

Tim buys many, many varieties of tomatoes and peppers every year. He concentrates on heirloom varieties. A few of his favorite seed companies include Johnny's Selected Seeds, Fedco and Seed Savers Exchange.

Propagation Facility/ System

Tim starts most of his transplants in a tunnel that is heated starting in late February. The plastic tunnel is covered in two layers of greenhouse plastic. Air blown between the layers of plastic creates a layer of insulation. He keeps the tunnel just above freezing to start at about 35 F and soon the tunnel is maintained above 50 F. He ends up using less than one 500 gallon propane tank to heat the tunnel most years.

Seeding and Pricking Out

The tomato and pepper seeds are started in 1020 trays (rectangular, flat bottomed trays) on heat mats that provide bottom heat. The trays are on shelved benches. This allows for more space in the greenhouse and keeps mice out of the germinating seedlings.

The tomatoes are pricked out into 72 count trays.

They also grow baby greens and radishes for early season production in 8" high raised beds. These beds run down the center of the greenhouse.

Soil Mix

Most of their transplants are grown in Pro-Mix with biofungicide. The biofungicide is bacillus subtillus a naturally occurring soil bacterium. This soil mix is NOT allowed for certified organic production. (Remember you cannot call your business organic if it is not certified if you make over $5,000 per year.)

They use a shrouder mix for raised beds in the greenhouse used to produce baby greens and radishes. The mix is made of topsoil and mushroom soil (compost). They add about an inch of new material per year to top off the beds.

Propagation Trays

They start their tomato and pepper seedlings in flat bottomed 1020 trays and prick them out into square 72 count flats.

Greenhouse pest management/ Sanitation

During the winter they open the entire greenhouse for around 3 weeks to allow mother-nature to come in and clean things out. They like to have things freeze pretty thoroughly during this time in order to help with this process.

In order to keep fungal problems at a minimum they sanitize their trays. They also use Pro-Mix which has a biofungicide – bacillus subtillus.

Aphids are their most common insect problem in the greenhouse. They order biological controls every year and have them on hand. As soon as aphids begin to appear they release lady bugs and parasitic wasps. They used A. colemani wasps this year. The wasps lay their eggs inside the bodies of the aphids and when the eggs hatch the larvae kill the aphids leaving a hollowed out husk behind.

Once it gets warm enough to pull the sides up, allowing air flow and natural predators to enter, aphids seem to be much less of a problem.

Rodents can also be a problem in the greenhouse. It is best to keep your seedlings on high benches Tim warned and make sure there is not something they can jump off of onto your bench near-by. Wire netting reaching up 2-3 feet on the sides of the greenhouse is essential to keep the groundhogs out when you start lifting up the plastic sides for ventilation.

Greenhouse irrigation

The greenhouse is irrigated using a simple hose and fine holed sprinkler head which is soft on the seedlings.

Eckerton Hill Farm, Lobachsville, PA Transplant Production

Planning

Tim tries to push his plants as early as he can. This helps him deliver early greens and tomatoes to his restaurant customers. You may not be making money at that point, but it keeps your customers happy and buying from you instead of your competitors early in the season. Because he is not aiming for a set date for harvest he has the flexibility to plant as soon as there is a window.

Advice to new farmers

Radishes are a nice early crop for greenhouses and tunnels. The French breakfast radish seems to do better than the round varieties and can give you a cash crop in 28 days. They plant them every 7-9 days in early spring for a continuous harvest. Micro radish greens can also work well. In eleven days you have micro-greens. They seed into trays of used potting mix and mushroom soil. Anything with a little juice seems to do well he says.

Spinach often will over winter in the tunnels and give you a nice early crop.

It is best to harden off your transplants for a week before you plant outside. Tim hardens off his plants on tables made from saw horses and hard wire cloth. Make sure your tables are distant from any structure to keep rodents from jumping onto them.

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, 2010.

Fleur-de-Lys Farm Market, Kutztown, PA Transplant Production

Fleur-de-Lys Farm Market in Kutztown, PA is a small family farm with naturally grown heirloom French, Italian, American, Asian and Mid-Eastern varieties. Laurie Lynch runs her farm with expertise and a flair for the unusual and interesting. She keeps the farm small in order to manage it herself and keep overhead at a minimum.

Seed Selection

Laurie is always looking for good flavor and something different when she searches the seed catalogs. She uses the old favorites like Fedco and Johnny's Selected Seeds but she also introduced me to a few I was not familiar with. Her new favorite is Pine Tree Gardens for their large selection of seeds available in small quantities at good prices. Bakers Creek and Gourmet Seed International were also on her list. Kitazawa offers a number of interesting Asian varieties.

Propagation Facility/ System

Laurie's neighbor starts her longs season crops like tomatoes, peppers and eggplants for her. A few 'cigar trays' (below) don't take much room in his greenhouse. This is much more efficient than Laurie heating greenhouse space for her small operation.

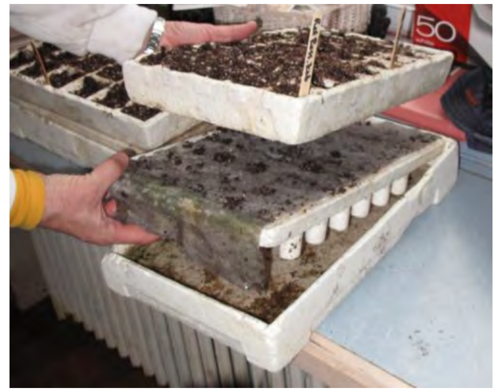
In Laurie's house there is a perfect spot for seed starting. The radiator under her kitchen windowsill (above) gives the bottom heat so many starting seeds and transplants love.

When seedlings are ready to leave her neighbor's greenhouse or the windowsill Laurie moves them out to her plastic tunnel (right). This is a very inexpensive type of tunnel to build (< $200). PVC pipes are secured by slipping over rebar protruding 2' from a wooden frame. End walls are built with plywood and 2x4s. Greenhouse plastic is stretched over the hoops. The tunnel does not retain a lot of heat at night but acts like a large cold frame.

This year Laurie tried hot boxes (left). She filled her cold frame with a layer of a mixture of manure from her lama, chickens and horses. Then she covered it with another layer of soil or potting mix and seeded greens. The rotting manure heats the cold frame and promotes seedling growth. She found that the cold frame where the manure was covered in potting soil was much less weedy than the other – a lesson for next year!

Soil Mix

Laurie uses a commercial soil mix from Farfard. It is NOT certified organic.



Propagation Trays

APS Styrofoam trays are a favorite of Laurie's. They wick moisture from the bottom tray and so they do not have to be watered every day. Unfortunately they may not be available any more.

Greenhouse Pest Management/ Sanitation

Laurie does not seem to have a large pest problem in her tunnel. She does worry about mice. She makes sure to keep both doors open once it warms up to ensure good airflow.

Greenhouse irrigation

Because the house and the water source are on the other side of the road Laurie keeps a 50 gallon barrel of water filled and waters from it with a watering can. When necessary she can run a hose across the road but the barrels are more convenient.

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Red Cat Farm, Germansville PA — Transplant Production

Teena Bailey runs Red Cat Farm in Germansville, PA. She specializes in greens, vegetable transplants and herbs as well as mixed vegetables which she sells to restaurants and local farmers markets.

Seed Selection

Teena offers a wide range of varieties of very high quality transplants in order to compete with other producers than can offer transplants at a lower price. In order to fill this niche she is constantly looking for varieties that no one else has. She orders seed from Johnny's Selected Seeds, Fedco, Harris and Parks Seeds. Totally Tomatoes is a favorite because they offer varieties that are not available elsewhere. Pine Tree offers unique varieties as well. Richters is a good one for herbs.

Propagation Facility/ System

Teena starts her transplants in her basement. They heat their house with a wood burning water heater. The 650 gallon water tank stays at 150-180 F. Flats seeded to tomatoes and peppers germinate there in three days or so due to the bottom heat. After 1-2 days under lights in the house she moves transplants out to her small tunnel onto her compost heated hot beds.

The propagation house is a home-made tunnel type structure. The frame is made of bent pipes.

Teena built her hot beds modeled on a system used by Steve Moore – the greenhouse guru. Using concrete bricks they built a wall 3' tall (4 bricks). The beds are filled every year with horse manure and bedding. She often adds additional fresh manure right out of the pasture or even chicken manure to make sure they are composting hot. She covers the hot compost with a sheet of weed barrier cloth and sets the transplant trays on top. The bottom heat keeps the plants warm even when the temperature outside is freezing. At night she covers the beds with corrugated plastic roofing propped with 2x4s and ceramic pots to provide ventilation. On very cold nights she adds a layer of plastic sheeting to trap the heat.

Soil Mix

Teena uses Pro-mix with biofungicide (bacillus subtillus, a naturally occurring soil bacteria) to start her tomato and pepper seedlings. Then she makes her own potting mix which she uses to prick all her transplants out into once they germinate. Her mix is 2 cubic yards of compost (from last year's hot beds), 1 scoop of pearlite, and 1 scoop of vermiculite.

Propagation Trays

Teena tends to start her seedlings in 288s because they were available locally from Meadow View Farm in Bowers, PA. The trays are nested in solid trays.

Seeding and Pricking Out

Teena transplants brassica plugs into 4 10s (10, 4 count packs fit per tray) because she sells transplants and the plants have to be happy in cells for a while. Tomatoes are in slightly bigger cell packs (8 fit per tray) because they have to remain in packs for longer before they are sold.

Supplemental Fertilization

She gives her transplants a shot of fish emulsion every 2 weeks. The fish emulsion solution is very dilute – about 1 Tablespoon per gallon. With the compost based mix this is usually all that they need.

Greenhouse Irrigation

She waters with a water wand on a hose. When it is really hot she also spritzes the cement blocks and this helps cool things down.

Greenhouse Pest Management/ Sanitation

Aphids are a problem in the greenhouse every year. Teena keeps them in check with 2 batches of lady bugs. The trick is to monitor constantly, she says. Sowbugs are also a problem this year. Teena is planning on using 'Slugo' (OMRI approved) this year, which is supposed to be effective on sowbugs. Screening open greenhouse ends is essential to keep roving chickens out.

Planning

In order to find her plantings dates Teena counts backwards from the frost free date. In Lehigh County that is May 15th. She counts back 6 weeks for tomatoes and 8 weeks for eggplants. She likes to plant brassicas out April 15th. They take 6-8 weeks, sometimes longer due to the lack of temperature control, so Teena starts them between Feb 15th and March 1st in order to get nice stalky seedlings for sale.

Advice!

Automatic vents save a lot of worry and headaches! The vents open automatically when the temperature rises due to a substance inside them that expands with temperature. (Available from Johnny's Selected Seeds).

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Department of Horticulture

Purdue University Cooperative Extension Service • West Lafayette, IN

Starting Seeds Indoors

*Michael N. Dana and B. Rosie Lerner**

Growing annual flowers and vegetables from seeds started indoors can be rewarding. Vigorous plants started indoors and then transplanted will flower sooner and produce an earlier harvest than those started directly outdoors. Home gardeners can also grow cultivars which may not be available from local nurseries as transplants.

Selecting Seeds for Planting

Purity and trueness to type—Good seeds should not contain seed of other crops or weeds and should be the correct cultivar. For best results, buy quality seed from a reliable dealer. In Indiana, vegetable seeds must meet minimum germination standards prescribed by law. If they fall below the legal minimum, the germination percentage must be shown on the package.

Packages and storage—Seeds sold in packages should show the crop, cultivar, germination percentage, and chemical seed treatments, if any. Seeds should be kept dry and cool to insure good germination at planting. Laminated foil packets insure dry storage. Paper packets are best kept in tightly closed cans or jars until seeds are planted.

Hybrid seeds—Many new vegetable and flower seeds are hybrids. Hybrid seed often costs more than seed of non-hybrid cultivars. However, hybrids usually have increased vigor, better uniformity, larger yields and sometimes specific disease resistance or other unique cultural characteristics. Each gardener must decide whether the added benefit justifies the added cost. It usually does.

Saving your own seed—Some experienced gardeners save their own seed. This practice requires the gardener to know the proper techniques for selecting, producing, handling, and storing the seed. Seed from hybrid plants should never be kept. Likewise, it may be unwise to keep seed from plants that are easily cross-pollinated, such as sweet corn, squash, and pumpkins. Bean seed may carry viruses and other diseases from one season to the next.

Containers for Sowing Seeds

Containers for starting seeds should be clean and sturdy and should fit into the space available for growing plants in the home. Having the proper container helps get seedlings off to a good start and may save work in later stages of seed development.

Wood flats, fiber trays, plastic trays—Plants that are easy to transplant may be seeded directly in flats or trays for later transplanting into individual pots or wider spacing in flats. Starting seeds in such containers saves space as compared to seeding directly into individual pots. However, where time is more important than space, direct seeding in pots may be preferred.

Clay and plastic pots—Both types can be cleaned and reused and are excellent for growing transplants. Plants to be transplanted must be removed, and the soil ball must be carefully cut apart at planting time. Seeds may also be planted directly into the pots.

Peat pots—These popular pots are made from peat or paper waste fibers and may be purchased individually or in strips or blocks. They are porous and provide excellent drainage and air movement. The entire pot can be planted, so there is minimum root disturbance at planting time.

Compressed peat pellets—When dry, expandable peat pellets are about the size of a silver dollar, but somewhat thicker. When placed in water, they swell to form a cylindrical container filled with peat moss, ready for seeding or transplanting. They may be planted directly into the garden. Use the pellets in trays so they are easily watered and held upright. Be sure they are placed so the open side is up.

Plastic flats, packs, and plugs—An increasing number of different types of plastic flats and packs are now being sold. In many types, you grow each plant in a cell and then merely “pop” it out at planting time. With care, these plastic flats and packs can be reused.

Soil Mixes and Other Growing Media

The medium used for starting seeds should be loose, well-drained, and of fine texture. You may use commercially prepared mixes or you may mix materials yourself.

Vermiculite—This material when used alone provides good seed germination. It is clean, and if not contaminated during handling, will not need sterilization. If other seeding mixes are used, it is useful for covering seeds. It does not form a crust, and seedlings can easily emerge. Vermiculite is available in several grades. For seeding, a fine grade is best.

Suggested Soil Mixture

Ingredients	1 gallon	1 bushel
Shredded sphagnum peat moss	2 qts	1/2 bu
Vermiculite #3, or 4	2 qts	1/2 bu
Limestone, dolomitic preferred	1 Tbsp	6 Tbsp
20% superphosphate (powdered)	1/2 Tbsp	2-1/2 Tbsp
5-10-5	—	7-1/2 Tbsp
Iron (chelated such as NaFe, 138 or 330)	—	1/2 tsp
Wetting agent[1]	—	1/2 tsp in 1/2 gal water

[1]Wetting agents or sufactants increase the ease of wetting peat moss and mixes high in organic matter. A small quantity added to water will help to uniformly distribute applied water. Dish detergent may be used as a wetting agent at double the recommended rate. Note: Bushels are level full, not packed. Tablespoons and teaspoons are level amounts.

Synthetic mixtures—Mixes that contain no soil are available for growing seeds. These contain either a combination of peat moss and vermiculite or peat moss and perlite. They may be purchased ready-made or can be mixed at home. These mixes as well as vermiculite used alone, have little fertility. Seedlings must be watered with a diluted fertilizer solution soon after they emerge. (See section on Fertilization under Growing Seedlings).

Soil-vermiculite mix—Seeds may be started in a mixture of about one-third loam garden soil and two-thirds vermiculite. Since good soil contains some fertility, prompt fertilization after germination is not essential. When garden soil is used, the mix must be sterilized before seeds are planted in it.

Soil-peat-sand-mix—Large seeds or vigorous-growing seeds may be planted in a mix of two parts loam garden soil, one part shredded peat moss, and two parts of either perlite, vermiculite, or sharp sand. Soil sterilization is necessary.

Milled sphagnum moss—A ground sphagnum moss is sometimes used for starting seeds, since it inhibits the seedling disease damping-off. It should be well-moistened before use. Since it contains no fertility, prompt fertilization is essential after seeds have germinated.

Layered mixes—Another technique used for germinating seeds is to partially fill a flat or pot with sterilized soil mix, and then top it with a layer of vermiculite or milled sphagnum moss in which the seeds are planted. After germination, roots of seedlings move from this top area into the soil mix, which provides fertility. Adding liquid fertilizer is less critical. Figure 1 illustrates this technique.

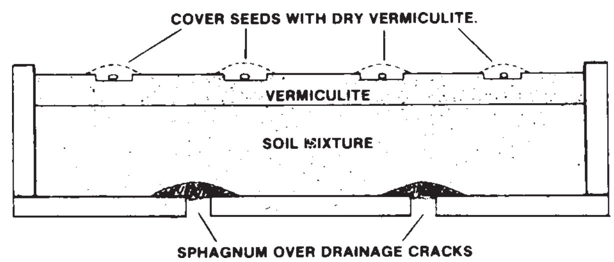


Figure 1. After germination, seedling roots move into the soil mix, which provides fertility.

Peat humus—Exercise caution using peat humus (or Michigan peat) in the place of sphagnum peat moss in seed germination mixes. There is wide variation in the water holding capacity, aeration characteristics and pH of the products sold under the name peat humus. It is safer to insist on sphagnum peat moss or used milled sphagnum moss.

Sterilizing Mixes and Containers

To guard against damping-off and other plant diseases carried in the soil and on containers, be sure to clean and sterilize materials.

Mixes—Place the moist, but not wet, soil mix in a container which can be covered to keep the soil from drying rapidly. If a cover is not available, use aluminum foil, and seal it down at the edges. The mixes may be sterilized directly in the pots or flats in which they are to be used. In addition to killing disease organisms, many weed seeds are killed by sterilization.

Pinch a small hole in the center of the foil, and insert the bulb end of a meat or candy thermometer into the soil so that the bulb is in the center of the soil mass. Place the pan in an oven at 200-220°F (93-105°C). Keep the soil in the oven until the thermometer shows a temperature of 160-180°F (71-82°C). Remove the pan and allow it to cool. Baking the soil will give off a strong odor, so some ventilation may be desirable. The time necessary for sterilization depends upon the volume of the soil, as well as its moisture content. Dry soil cannot be sterilized well.

Some home gardeners prefer to place a raw potato in the center of the soil and bake in a medium oven until the potato is done.

After the soil has been sterilized, make sure the containers, tools, and working area are also clean and sterile. Clean soil can be easily re-infected by careless techniques. *In sterile soil, reintroduced diseases may spread faster than they would in unsterilized soil*.

Containers—All containers that have been used should be washed thoroughly in soapy water to remove all debris. Do not put wooden flats or plastic containers in the oven. Rinse wood and plastic items in a solution of one part chlorine bleach and ten parts water. Let them dry before filling with soil.

Seed—Many seeds are pre-treated with a fungicide to protect the seed from diseases such as damping-off. These seeds may be dusted with a white, pink, green, or blue color fungicide. If seeds have not been treated, dust them with a fungicide before sowing. Be sure to wear gloves when handling the fungicide.

Seeding

The proper time for sowing seeds depends upon when plants may normally be moved outdoors. The periods range from 4 to 14 weeks, depending upon the speed with which seedlings grow and the conditions in the home (see Table 1). *Read the label on the seed packet for any planting directions*.

1. Fill the container to within 3/4 inch from the top with the mixture to be used. If it is dry, moisten the mixture before filling. Make sure that the container has adequate drainage. Before filling, cover holes or cracks in the container with sphagnum moss or broken crockery.

2. Level and gently firm the planting medium. Use a clean small board for leveling and firming. Do not press too hard in firming the surface or poor aeration and decreased root growth will result.

3. Make shallow rows about 1-2 inches apart in the flat using a narrow board or large wooden marker label (Figure 2). When different seeds are used in the same container, they are easier to keep track of if planted in rows. If only one type of seed is used in each flat, then seed may be scattered or broadcast over the surface.

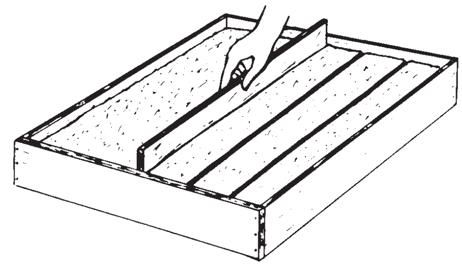


Figure 2. A shallow row about 1 to 2 inches apart in a seed flat.

4. Sow seeds uniformly and thinly in the rows. Many small, round seeds may be slowly dropped into the rows by tapping the package as it is held over the rows (Figure 3). Label each row promptly with plant type, variety, and date of planting. Use pencil or waterproof pen for labeling.

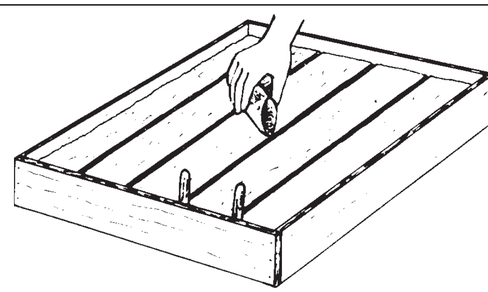


Figure 3. Round seeds may be slowly dropped in the rows by tapping the package as it is held over the rows.

Plant large seeded vegetables, such as cucumber, muskmelon, and watermelon, directly into peat pots. Other seeds may also be handled this way to save transplanting, but sowing is difficult with very small seeds. Plant two seeds per pot and later thin to one plant. This saves later transplanting and means less root damage at planting time.

5. Cover the seeds with dry vermiculite or milled sphagnum moss. The depth of covering depends upon the size of the seeds. Very fine seeds, such as petunia or begonia, should not be covered. Moisten the surface with a fine mist, or place the container in a pan of warm water to absorb moisture from the base. Do not place containers in water that is deep enough to run over the top of the pot or flat. It may mix seeds or cover them too deeply. Bottom watering helps avoid damping off by keeping the soil surface dry. As a general rule, seeds other than very fine seeds should be covered with soil to a depth of about two times their diameter.

6. Cover the container with polyethylene plastic film (a clear bag will do) or a piece of window glass. Since they retain moisture, no additional watering should be necessary until after seeds have germinated.

7. Place seeds in a warm location for germination. Generally a temperature range of 65-75°F (18-24°C) is best. A few plants, such as larkspur, snapdragon, sweet pea, cabbage, broccoli, and cauliflower, are best started at about 55°F (13°C). *Do not place covered containers in direct sunlight.*

8. Watch daily for germination. Move to bright light, and remove plastic or glass coverings as soon as germination is well underway. If all seeds do not germinate at the same time, cut strips of plastic or cloth and keep ungerminated rows covered until seedlings appear. Seeds are quickly killed if allowed to dry during germination. Watch closely for development of damping-off, and control promptly.

After germination, place those plants listed as preferring cool temperatures in cool location.

Damping-Off

When seedlings fall over at the groundline, they are being attacked by a fungus disease known as damping-off. If only a few seedlings are attacked, dig out and discard the infected plants and soil, taking care to dig well into the uninfected portion of the soil. Drench the entire soil mass with a fungicide if the disease is scattered throughout the flat or pot. This may not provide complete control. High temperature, poor light, or excess moisture stimulate spread of the disease by weakening plants to make them more susceptible to it. The best control is cleanliness and prompt action when the disease appears.

Growing Seedlings

After seeds have germinated, they must be promptly given the best possible growing conditions to insure stocky vigorous plants for outdoor planting. Cultural requirement must be considered carefully.

Light—Seedlings must receive bright light promptly after germination. Place them in a bright south window if possible. If a large, bright window is not available, place the flats under fluorescent lights. A fixture containing two fluorescent tubes is adequate. Use a combination of 1 cool white tube and 1 warm white tube. Place the seedlings 3-4 inches from the tubes, and keep lights on for 14-16 hours each day. An automatic timer is useful.

Be aware that fluorescent tubes produce poorer light quality and lower light intensity with age. If seedlings are correctly placed under lights and become spindly, it is probably the fault of old fluorescent tubes. Two years is a typical bulb life. New lights will alleviate this problem. As seedlings grow, the lights may need to be raised to prevent leaf burn as seedlings touch the tubes.

Temperature—Most annual plants and vegetables prefer night temperatures of 60-65°F (15-18°C). Day temperatures may run about 10°F higher. If temperatures are warmer than this, leggy plants result. Cool season vegetable crops and a few flowers prefer night temperatures no higher than 55°F (13°C) and day temperatures near 65°F (18°C). An unused bedroom, basement, or sunporch is often a good location.

Moisture and watering—Good air humidity is an asset for producing good plants. A humidifier may be placed as close to the growing area as possible. Flats should never be over-watered. Allow drying between waterings, but do not allow seedlings to wilt at any time.

Fertilization—Seedlings will need some fertilization for best development. Those in totally artificial mixes without fertilizer need prompt and regular fertilization. Use a soluble house plant fertilizer such as 15-30-15 or similar analysis. Young, tender seedlings are easily damaged by too much fertilizer. Apply fertilizer at about half of the recommended strength a few days after seedlings have germinated. After that, fertilize at 2-week intervals with the dilution recommended by the manufacturer.

Transplanting and Thinning

As soon as seedlings have developed at least one set of true leaves and are large enough to handle, they should be transplanted to individual pots or spaced out in flats. Failure to transplant promptly results in crowded, spindly seedlings that will not develop properly. If a hotbed is available, seedlings may be transferred directly to it. Artificial mixes or a soil mix of one part soil, one part sphagnum peat and one part sand may be used.

To transplant, carefully dig up the small plants with a knife, spatula, or wooden label. Let this group of seedlings fall apart, and pick out individual plants. Occasionally if seedlings have been too close, they are difficult to separate. Gently ease them apart in small groups which will make it easier to separate individual plants. Avoid tearing roots in the process. Handle small seedlings by their leaves; small thin stems break and crush easily.

Poke a hole into the soil where the seedling will be planted. Make it deep enough so that the seedling can be put at the same depth it was growing in the seed flat. Small plants or slow growers may be placed 1 inch apart and rapid growing, large seedlings may be positioned about 2 inches apart. After planting, firm the soil and water gently.

If seeds were sown in individual peat pots or pellets, thin to one seedling per pot at this time. Do not pull the extra seedling out as this will disturb the roots of the remaining seedling. Simply cut it off with scissors.

Keep newly transplanted seedlings in the shade for a few days, or place them under fluorescent lights. Keep them away from heat sources. Continue watering and fertilizing as was done in the seed flats.

Vegetables easily transplanted include broccoli, cabbage, Brussels sprouts, lettuce, and tomatoes. Those with a little slower root development include cauliflower, celery, eggplant, onion, and pepper. Plants that do not transplant well and therefore are seeded in individual pots include cucumber, muskmelon, squash, and watermelon.

Most flowers normally grown indoors transplant well, but a few that are difficult to transplant include poppy, larkspur, lupine, sweet pea, and cornflower. These are generally seeded outdoors; but to start them indoors, place them directly into individual pots.

Pinching

Most annual flowers respond to pinching, which encourages side branching. Usually the top inch or two is removed from the growing tip, leaving 3 or 4 leaves. *Do not pinch vegetable plants.*

Moving Plants Outdoors

Hardening—Plants which have been growing indoors cannot be planted abruptly into the garden without danger of injury. To prevent damage, they should be hardened before planting outdoors.

This process should be started 2 weeks before planting in the garden. If possible, plants should be moved to cooler temperatures outdoors in a shady location. A coldframe is excellent for this purpose. When first put outdoors, keep in the shade, but gradually move plants into sunlight for short periods each day. Gradually increase the length of exposure. Do not put tender seedlings outdoors on windy days or when temperatures are below 45°F (7°C). Reduce the frequency of watering to slow growth, but do not allow plants to wilt. Even cold-hardy plants such as cabbage and pansy will be hurt if exposed to freezing temperatures before they have been hardened. After proper hardening, however, they can be planted outdoors and light frost will not damage them.

Planting into the garden—When plants have grown large enough to handle easily and hardening is complete, they may be planted into the garden when weather conditions permit.

Carefully remove plants from the growing flats, retaining as much soil as possible around the roots. Dig the hole about twice as large as the soil mass around the roots. Set the plants at about the same level they have been growing in the pots. A few plants such as tomato and marigold are able to develop roots along the stem. If they have become leggy, they may be planted deeper than they were previously growing. Place soil loosely around the roots, and apply about one cup of a starter fertilizer solution. This solution is made by dissolving 1 tablespoon of high-phosphorus fertilizer in 1 gallon of water. A 15-30-15 or similar analysis is satisfactory.

Plants grown in clay and plastic pots must be removed from them before planting. Those growing in peat pots or peat pellets can be planted intact. Breaking the base of the peat pot often helps improve root penetration and drainage. Make sure that the top edges of the pot are thoroughly covered or removed. If not covered, the edge may act as a wick and evaporate moisture from the root ball. This evaporation delays root penetration or even causes the plant to dry up on hot sunny days.

Transplant on cloudy days if possible. In warm, sunny weather, cover the newly planted seedlings with newspaper tents or some other type of shading for 2 or 3 days until they are well-established.

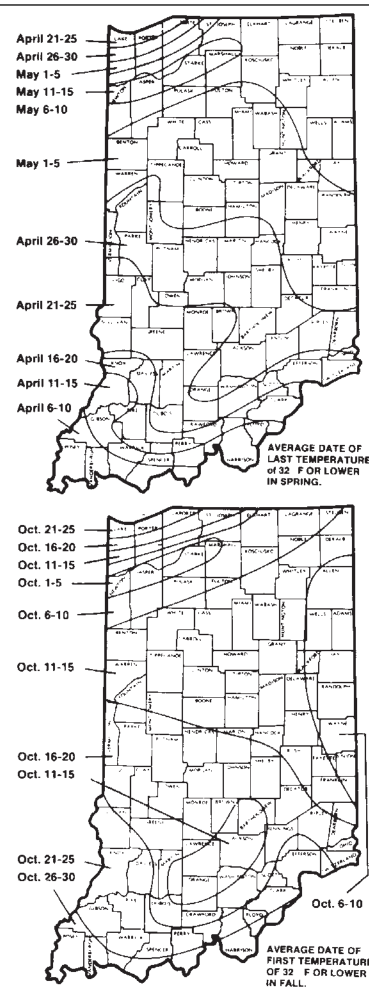


Figure 4. Dates, probabilities, and low temperatures.

Table 1. Guide to sowing vegetable and annual flower seeds in the home.

Time to Seed Before Last Frost	Plant Types	Germination Time (days)	Growth Rate	Cold & Frost Tolerance After Hardening
		VEGETABLES		
10 weeks	Broccoli*	6-10	medium	good
10 weeks	Cabbage*	6-10	medium	good
10 weeks	Cauliflower*	6-10	medium	good
10 weeks	Head lettuce	3-5	medium	good
7 weeks	Tomato	6-10	medium	none
7 weeks	Eggplant	7-14	medium	none
7 weeks	Pepper	7-14	medium	none
4 weeks	Cucumber	4-6	fast	none
4 weeks	Cantaloupe	4-6	fast	none
4 weeks	Squash	4-6	fast	none
4 weeks	Watermelon	4-6	fast	none
		FLOWERS		
14 weeks	Begonia	10-12	slow	none
14 weeks	Pansy	6-10	medium	good
14 weeks	Violet	6-10	medium	good
12 weeks	Lobelia	15-20	slow	none
12 weeks	Stocks	10-14	medium	good
11 weeks	Black-eyed Susan vine	10-12	slow-medium	none
11 weeks	Impatiens	15-18	medium	none
11 weeks	Torenia	10-15	medium	medium
10 weeks	Petunia	6-12	slow-medium	slight
9 weeks	Ageratum	5-8	medium	none
9 weeks	Scabiosa	8-12	medium	slight
9 weeks	Snapdragon	7-12	medium	medium
9 weeks	Verbena	12-20	medium	slight
8 weeks	Bells of Ireland	21+	medium	medium
8 weeks	Dianthus	5-7	medium	medium
8 weeks	Salpiglossis (Painted Tongue)	8-10	medium	none
8 weeks	Vinca (Periwinkle)	10-15	medium	none
8 weeks	Scarlet Sage (Salvia)	12-15	medium	none
8 weeks	Statice	15-20	medium	slight
7 weeks	Nicotiana	10-15	medium	slight
7 weeks	Nierembergia	10-15	medium	slight
7 weeks	Phlox, Annual	6-10	medium-fast	none
7 weeks	Sweet Alyssum	4-8	fast	slight
6 weeks	Aster	8-10	medium	slight
6 weeks	Balsam	6-8	medium-fast	none
6 weeks	Celosia (Cockscomb)	6-10	fast	none
6 weeks	Cornflower	6-10	fast	good
6 weeks	Marigold	5-7	fast	none
6 weeks	Portulaca	6-10	fast	none
4 weeks	Cosmos	5	fast	none
4 weeks	Zinnia	5-7	fast	none

*Note: These vegetables are commonly grown as fall crops as well as spring/summer transplants. Start seeds 5-7 weeks (7-9 weeks for cauliflower) before plant out date. Planting out date depends on length of season for your particular cultivar and the date of first frost for your location(see Figure 4). It will usually be between July 15 and August 1.

*This publication was originally authored by M. N. Dana and Allen E. Boger, Retired Extension Educator, Allen County.

For more information on the subject discussed in this publication, consult your local office of the Purdue University Cooperative Extension Service.

Soil Quality

Healthy soils yield healthy crops, to paraphrase Robert Rodale founder of the organic movement. But what is healthy soil and how do we achieve it?

Soil health is the foundation of productive farming practices. Fertile soil provides essential nutrients to plants. Important physical characteristics of soil-like structures and aggregation allow water and air to infiltrate, roots to explore and biota to thrive. Diverse and active biological communities help soil resist physical degradation and cycle nutrients at rates to meet plant needs. Soil health and soil quality are terms used interchangeably to describe soils that are not only fertile, but possess adequate physical and biological properties to "sustain productivity, maintain environmental quality and promote plant and animal health [5]."

"Soil quality is how well soil does what we want it to do" [6]. In order to grow our crops, we want the soil to hold water and nutrients like a sponge where they are readily available for plant roots to take them up, suppress pests and weeds that may attack our plants, sequester carbon from the atmosphere and clean the water that flows through it into rivers, lakes and aquifers.

Remember, soil fertility is only one component of soil quality. Fertile soils are able to provide the nutrients required for plant growth. These are the chemical components of soil. There are nutrients that plants need in large amounts like nitrogen, phosphorus and potassium called macronutrients, and others plants only need in very small amounts like boron and manganese. In high quality soil, nutrients are available at rates high enough to supply plant needs, but low enough that excess nutrients are not leached into ground water or present at high levels toxic to plants and microbes. *For more information on soil fertility, see Start Farming Fact 2– Managing Soils.*

All of these characteristics sound great. But when you look at your field, how do you tell whether you have high quality soil and how do you improve it? The first step is to learn about the properties of your soil. The following describes soil properties and indicators of soil quality that are important for healthy, productive crops. Indicators are things that we can easily measure that allow us to see what is happening in soil.

Healthy, high quality soil has:

Good soil tilth.

Sufficient depth.

Sufficient, but not excessive, nutrient supply.

Small population of plant pathogens and insect pests.

Good soil drainage.

Large population of beneficial organisms.

Low weed pressure.

No chemicals or toxins that may harm the crop.

Resilience to degradation and unfavorable conditions [4].

Soil Texture

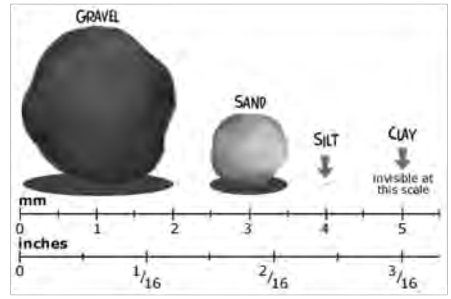
There are certain aspects of a given soil that we cannot change. Soil texture is one such aspect. Soil texture is a good place to start when you look at your soil. When you understand your soil's texture, you know more about the restrictions there might be on your particular piece of land and any possible advantages.

The terms sand, silt and clay refer to particle size – sand is the largest and clay is the smallest. Gravel particles are larger than 2 mm, sand particles are 0.05 to 2 mm, silt particles are 0.002 to 0.05 mm and clay smaller than 0.002 mm. To put this in perspective, if a particle of clay were the size of a BB, then a particle of silt would be the size of a golf ball and a grain of sand would be the size of a chair [7].

Even though the definition is based on particle size, the shape of the particles is important for thinking about how soil texture relates to soil quality. Sand particles are generally round, while silt and clay particles are usually thinner and flatter. In a soil with larger round particles, there is more space for water and air that our plants need. In a soil with larger round particles the air space between the particles is larger, providing good aeration. However, in a sandy soil, many of the air spaces are too large to hold water against the force of gravity, creating a soil with low water holding capacity that is prone to drought.

How do I tell what texture my soil is? You can determine a soil's texture by how the soil feels. Does it feel gritty, greasy or floury? Gritty soils are sandy. Silty soils feel floury when they are dry and greasy when they are wet. Clay will always feel greasy. Take a small handful of soil and drop enough water on it that you can form a ball. When you rub it in the palm of your hand, it will fall apart and you will feel the grit rub into your palm if it is sand. A silt will form a ball, but when you try to roll it out into a ribbon it will crack. A clay soil will roll out into a long ribbon.

Differences between sand, silt and clay You are probably familiar with the characteristics of a clay soil. We call them heavy soils for a reason. They can be difficult to work. They dry out slowly and when they do dry out they can leave a hard crust that does not allow the rain to penetrate. But let's explore why clays act this way. Clays are made up of very small particles. Some kinds of clay are layered together in sheets. Think of a piece of baklava or a deck of cards with many thin layers stacked on top of each other. Clay can hold water and nutrients between those fine layers. Another important aspect of clays is that each of these individual layers have many "parking spaces" for plant nutrients. In reality, these "parking spaces" are negatively charged sites on the surface of the layer, as well as within the structure of the clay layer. Many of the nutrients are



To put particle size in perspective, if a particle of clay were the size of a BB, then a particle of silt would be the size of a golf ball and a grain of sand would be the size of a chair.

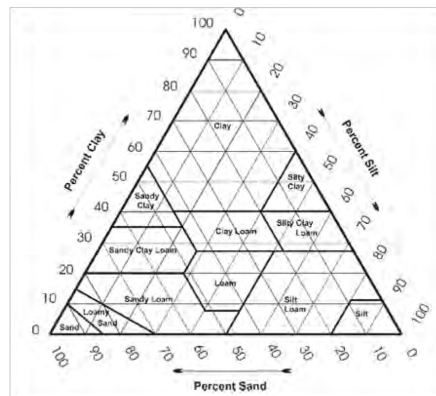


Illustration Courtesy Clay Saylers.

Soils Texture Triangle shows different amounts of water and air in soil with different size and shape particles.

positively charged (called CATIONS), and, therefore, attracted to the negatively-charged "parking space" just like the opposite ends of a magnet are attracted to each other [8].Tiny clay particles have more surface area than larger particles of sand or silt. That means there is more area for positively charged plant nutrients to stick to.

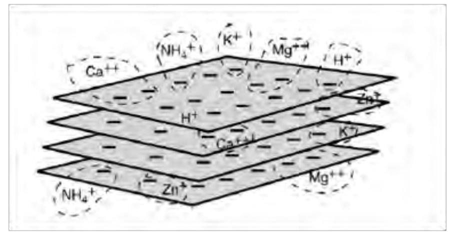
Sand is loose and single grained. The individual grains can be easily seen and felt. If you take a handful of dry sand and squeeze it, it will fall apart. If you squeeze it when it is wet, it will form a cast and then crumble when you touch it. Loam is a mix of sand, silt and clay. It is mellow with a somewhat gritty feel, yet fairly sticky and slightly plastic [7].

Soil Structure

In pursuit of high quality soil, we generally try to build highly "structured" soils. While the texture of the soil is inherent and difficult, if not impossible to change; we can influence the structure of the soil with our management practices. When we plow, cultivate, lime, add organic matter and stimulate biological activity, we change soil structure.

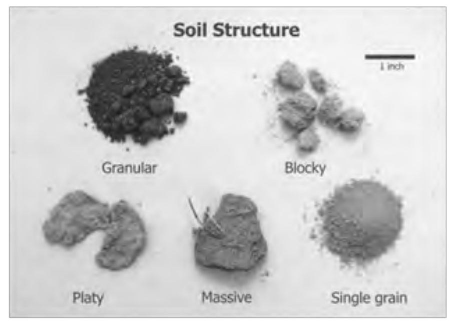
Whereas texture is the composition or relative proportion of three soil particle types (sand, silt, clay), soil structure is the arrangement or the geometry of these soil particles [8, 9]. Soil with good structure has a wide range of pore spaces or empty space between the soil particles. For example, in a good loam soil 40 to 60% of the soil volume is pore space filled with air and water [8].

To understand this concept, compare your soil to a building. If a building is made out of bricks, the "texture" of the building would be the proportion of cement, sand and brick (clay, silt and sand) that make up the building. The "structure" would be the arrangement of these bricks to form large rooms, small rooms and hallways, etc. If an earthquake should cause the building to collapse into a pile of bricks, the "texture" would remain the same, but the "structure" would have been radically altered. To follow on our analogy, just as before the earthquake the "structure" of the building provided much better living conditions than after (big and small rooms in which to move and live), similarly, a soil that has a good structure provides better living conditions for soil organisms and roots. It has many large and small pore spaces through which air, water, roots and living organisms can move freely [8]. Soil scientists call soils with good structure "granular" or "crumb" type soils [9]. These soils are loose and fluffy. Generally they are high in organic matter and have large soil aggregates. Think about



Some clays hold water and nutrients between fine layers. Negative charges act like "parking spaces" holding positively charged plant nutrients in place.

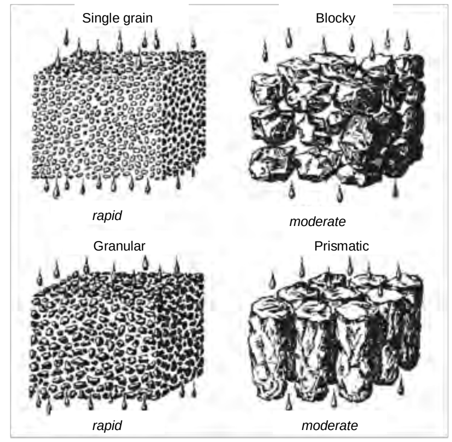
Illustration FAO, Farmer Field Schools



Soil particles are arranged in different ways to constitute the soil's structure.

what the soil looks like when you dig under a thick layer of sod. It has many crumbly pieces, large pores, clumps, roots and decaying pieces of organic material.

In contrast, platy soils have thin layers of horizontal plates or leaflets. These plates are often inherited by the way the soil was formed. But we can also create them by over use of heavy machinery on clayey soils [9]. Deeper soil layers may be prisim-like, columnar or block-like. We don't generally change the structure of deeper soil layers with our management practices, but it is good to check the soil survey to find out what lies beneath your soil layer because it may affect drainage and root penetration [9].



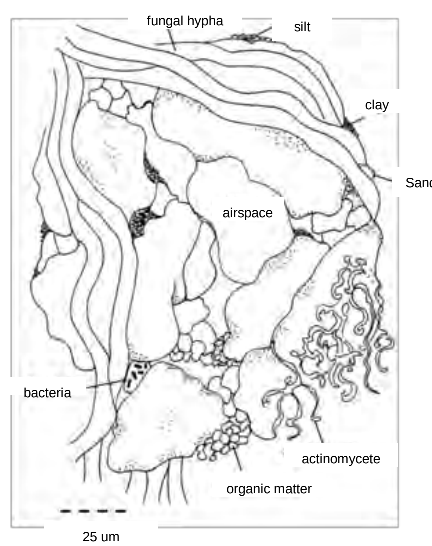
Soil structure affects how quickly water moves through soil. Water moves quickly through soils with many small grains. Soils with larger aggregates in the form of blocks or prisms have moderate drainage.

Soil Aggregates

The aspect of soil structure that often interests us most as soil managers and we can most easily change is soil aggregation. Bacteria and roots produce sticky substances that glue soil particles together. Fungi and root hairs wrap soil particles into balls. These groups of soil particles are called aggregates.

One important type of soil aggregate are water stable aggregates. Aggregate stability is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops [4].

Why does it matter? The number of water stable aggregates in your soil show its capacity to sustain its structure during the most impactful conditions: a heavy rain storm after weather dried the surface. Soils with low aggregate stability can constrict crops because they: form surface crusts which can reduce both water infiltration and air exchange; make the soil more difficult to manage, and reduce its ability to dry off quickly; and often have low biological activity. Aggregates are formed in part by
exudates from bacteria, entanglement of soil particles in fungal hyphae and digestion by earthworms. Low biological activity means reduced mineral cycling and competition with pest organisms [4].



Bacteria and roots produce sticky substances that glue soil particles together. Fungi and root hairs wrap soil particles into balls called aggregates.

Illustration S. T. DuPont, PSU.

How can I improve it? As soil managers we can help soil build aggregates by growing green manure cover crops or adding animal manure. Also think about your tillage regime. Over the long term, repeated tillage of soil can reduce soil tilth and break down stable soil aggregates. Such soils can be so degraded that they become addicted to tillage and crop establishment requires a soil loosening operation. If you can reduce your tillage operations, you may reduce the disturbance to the soil biota that are essential for building aggregation. Feeding the soil food web with cover crops or other organic materials also increases the numbers of these organisms. Then bacteria and fungi work to help make aggregation happen [4].

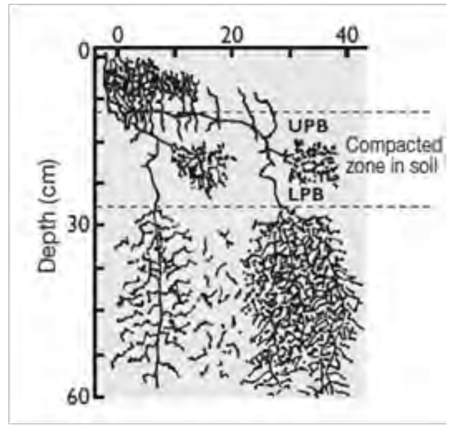
Compaction

When soil has poor soil structure or we mistreat it, we compact the soil. A good loam soil is about 50% soil particles and 50% pore space filled with air and water [9]. When we run over the soil when it is too wet or with too heavy of equipment, we are pushing the soil particles closer together. As a result, the pores are small and can hold less air and water for plants. When soils become extremely compacted, roots can no longer penetrate the soil. Compacted soils have fewer and smaller roots. In a normal soil, crop roots are only in contact with less than 1% of the total soil volume. The roots have to be able to continually grow and explore to find new nutrient reserves and water needs to be able to move easily through the soil where it can reach roots and wash nutrients to where roots are. Compaction not only directly affects root growth, it also reduces the amount of air filled pores and thus oxygen in the soil. The increase in CO_2 in relation to oxygen can be toxic. For more information see references [1, 10, 11].

Managing soil compaction, can be achieved through appropriate application of some or all of the following techniques: (a) addition of organic matter; (b) controlled traffic; (c) mechanical loosening such as deep ripping; (d) selecting a rotation which includes crops with strong taproots able to penetrate and break down compacted soils. Deep ripping can reduce compaction initially. Unfortunately, unless it is combined with additions of organic matter or reduction in traffic, the benefits of ripping may only be seen for one to two years before the soil settles and re-compacts [4].

High quality soils have a high available water holding capacity. Plants are like people, right? They need food, water and oxygen to grow. Soils with a high available water holding capacity have a larger reservoir and can supply water over time when plants need it. Technically a soil's available water holding capacity is the amount of water the soil can hold between field capacity (after gravity has drained the soil) and the permanent wilting point. So what is field capacity? Imagine you just had a heavy rain that fully saturated the soil. Then you wait 2 days just until the point that the soil has stopped draining. That is field capacity. The permanent wilting point is defined as the soil moisture level at which a wilted plant cannot recover even after 12 hours in a re-moistened soil. So available water holding capacity is the amount of water a soil can hold between when it is fully saturated but drained, and when it is so dry that plants die.

Clay and sandy soils will have different water holding capacity.



Roots occupy a larger soil volume in non– compacted soil layer (30-60 cm) than in compacted soil (15-30 cm).

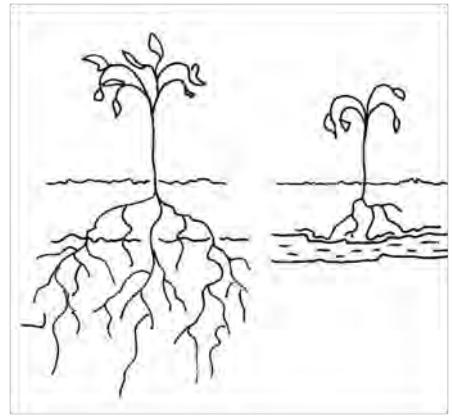
Adapted from Keisling, T. C., J. T. Batchelor, and O. A. Porter. 1995 "Soybean root morphology in soils with and without tillage pans in the lower Mississippi River Valley." *Journal of Plant Nutrition* 18:373–384 by Duiker, S. 2004 [1].

Soil compaction causes reduced infiltration.

Photo Duiker, S. 2004 [1].

The available water holding capacity is an indicator of how much water the soil can store. Sandy soils often cannot store as much water for crops between rains.

How can I improve its water holding capacity? The addition of organic matter to soils either from manure, compost or cover crops can improve the soils capacity to hold water. In the short term, you may want to consider adding stable organic materials like compost or crop residue high in lignin or cover crops high in carbon. In the long term, rotation to sod and reduced tillage are known to help.



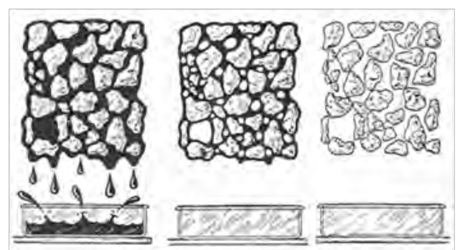
Plant root growth is limited in compacted soils.

Illustration S.T. DuPont.

Organic Matter

Soil organic matter (SOM) is a complex of diverse components including plant and animal residues, living and dead soil microorganisms, and substances produced by these organisms and their decomposition. SOM influences the chemical, biological and physical properties of the soil in ways that are almost universally beneficial to crop production. The most common sources of SOM in farming are crop residues, cover crop residues, manures and composts.

Why is soil organic matter so important? This tiny fraction of the soil volume (agricultural soils average 1 to 6%) has an overwhelming influence on most other soil properties. Often classified as "the living, the dead and the very dead," it is composed of three components – living organisms, fresh residue and well decomposed residue. Each of these components contribute to the vital functions of soil.



(a) (b) (c)

a) Saturated Soil
b) Field Capacity
c) Permanent Wilting Point

Bacteria, fungi, protozoa, earthworms, tiny insects and other organisms form the living fraction of soil organic matter. Much to the surprise of anyone who considers soil to be dead dirt, living organisms compose about 15% of total soil organic matter [2], weighing between 2,000 and 30,000 lbs per acre [7]. This live fraction of the soil does a host of functions described below.

The second fraction of soil organic matter is the "dead" – fresh residues that have been recently added to soil. This is active, easily decomposed material that provides the fuel for soil organism. When fresh SOM is added to the soil, most of it decays to CO_2, H_2O and minerals within a few months to years. This process provides energy (e.g., via respiration) for soil microbes and mineral nutrients for both microbes and plants (e.g., crops). Just like cornflakes provide sugar and carbohydrates for humans, decaying leaves, manure, and plant roots provide sugars and carbohydrates for bacteria, fungi and the soil food web.

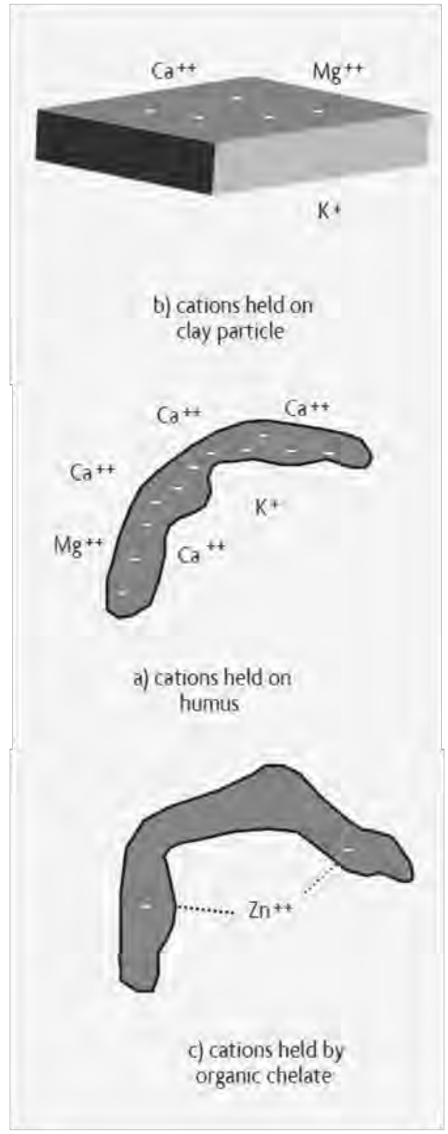
Some soil organic matter is very resistant to (further) decay and can last (often bound tightly to clay particles) for hundreds of years. This very stable form of SOM is commonly referred to as humus. In fact the average humus particle is 1,000 years old [2]. Humus is typically about 70% of the total SOM in agricultural soils. Humus, in particular, and SOM, in general, are important in enhancing soil nutrient (especially cation) holding and water holding capacities, soil structure and tilth and general fertility. Organic matter management is an important part of farming, but our understanding of it is quite elementary. We know that soil fertility tends to increase with increasing SOM and continual depletion of SOM eventually leads to very poor soils.

Soil Biota

The soil is alive. In just one teaspoon of agricultural soil there can be 100 million to 1 billion bacteria, six to nine feet of fungal strands put end to end, several thousand flagellates and amoeba, one to several hundred ciliates, hundreds of nematodes, up to 100 tiny soil insects and five or more earthworms. These organisms are essential for healthy growth of your plants. For example, tiny insects in the soil rip and shred leaves and other organic material breaking it down into smaller pieces that are then consumed by bacteria and fungi. These bacteria and fungi excrete sticky substances that hold the soil together into aggregates and provide food for an entire web of organisms in the soil. When these bacteria and fungi are consumed by other soil organisms, like the microscopic worms called nematodes, the nematodes excrete ammonia, an important source of nitrogen for plants.

Adding organic matter to soil is essential for all of these soil organisms. Cover crops, leaves, compost – and other organic materials that we add to soil – are the food for these organisms. Which type of organic material we add to soil changes which type of organisms will have the largest numbers. For example, adding material very high in carbon will encourage fungi who excrete enzymes such as chitinase which can break down tough to digest material.

1. Duiker, S.W., Effects of Soil Compaction. 2004, Penn State College of Agricultural Sciences, University Park, PA.
2. Gugino, B.K., et al., Soil Health Training Manual, Cornell, Editor. 2007: Ithaca, NY.
3. Doran, J.W., et al., Defining Soil Quality for a Sustainable Environment. SSSA Special Publication: Soil Science Society of America Journal, 1994. 49.
4. USDA. Soil Quality Concepts. Available from: http://soils.usda.gov/sqi/concepts/concepts.html
5. Russell, E., Soil Texture Descriptions, in Teaching Organic Farming and Gardening, A. Miles and M. Brown, Editors. 2005, University of California: Santa Cruz.
6. FAO, Farmer Field Schools The Soil System. 2007.
7. Brady, N.C. and R.R. Weil, The Nature and Properties of Soils. 11th edition, 1996, Upper Saddle River, NJ: Prentice Hall.
8. Duiker, S.W., Diagnosing soil compaction using a penetrometer (soil compaction tester): Agronomy Facts 63. 2002, Penn State College of Agricultural Sci-



Cations held on negatively charged organic matter and clay.

From *Building Soils for Better Crops* pg 15.

Managing Soils

The goal of good soil management is to meet essential plant needs for water, nutrients, oxygen and a medium to hold their roots with as little "management" as possible.

Plants need water, nutrients, carbon, oxygen and a medium to hold them up. All of our actions managing soils will affect these components. For example, when we add compost, plant residue or cover crops to the soil we are feeding the soil microbes. These microbes exude sticky substances which hold the soil structure together and protect soil organic matter. When we till, we integrate organic material into the soil where it can break down, but also "burn" off organic matter by stimulating microbes that breathe out carbon.

The following section briefly outlines some considerations for new soil managers.

Managing for Optimal Oxygen and Water in Soil

Plants need oxygen and water to grow. By forming and maintaining soils with good soil tilth, e.g., many large soil aggregates, and high organic matter content, we maintain the correct balance of pore space in the soil filled with air and water to soil particles. (See *Introduction to Soils—Fact 1*.)

One goal of soil cultivation is to maintain good soil structure and tilth. The first time you go through a field each season with a plow or disk is called primary tillage. This cultivation loosens and opens the soil aiding root penetration and aerating the soil. Remember a good loam soil has about 50% soil and 50% pore space. Tillage increases air/gas exchange with the atmosphere. Not only plants, but soil organisms, need this oxygen. When you till and integrate both oxygen and organic matter, you stimulate biological activity, causing microbes to decompose the plant material into the nutrients plants need [12].

Primary tillage allows you to integrate cover crops, compost, other organic material and mineral amendments into the soil. Without tillage, cover crops and residue form a thin layer of highly organic material on the surface of the soil, instead of being distributed throughout the soil profile.

The plow is one of the most valuable of human inventions. But long before it existed, the land was, in fact, regularly plowed, and continues to be thus plowed, by earthworms.

- Charles Darwin, 1881

Excessive tillage:

- Decreases organic matter
- Reduces biological activity
- Destroys aggregates
- Reduces nutrient holding capacity
- Restricts drainage
- Diminishes pore space

Whatever the cause of soil unthriftiness, there is no dispute as to the remedial measures. Doctors may disagree to what causes the disease, but agree as to the medicine. Crop rotation! The use of barnyard and green manuring! Humus maintenance! These are the fundamental needs."

- Hills, Jones and Cutler, 1908 [2].

Cultivation can also break up compaction layers. Deep tillage physically fractures the soil. Of course, one of the most important reasons for tillage is weed control. Primary cultivation buries weeds that may have grown up during the winter. This is especially important in organic systems. Organic row crop producers in Pennsylvania found that when they used tillage that was less aggressive, such as the chisel plow, weeds in soybeans and corn were difficult to control. In contrast, when they used a moldboard plow, they did not have as much weed pressure.

Possible Impacts of Excessive Tillage

Like most things, tillage can be good in moderation. However, it is essential that you think about when you till, how often you till and how well you balance your tillage with organic matter inputs.

Tillage reduces soil organic matter content by a process called oxidation. Usually, the amount of oxygen in the soil limits the activity and number of soil microbes. When we till, we mix in oxygen, and bacteria and fungi multiply. When you consider that some bacteria can double their population in ten minutes, their populations increase quickly. This “bloom” of bacteria and the slightly slower increase in fungi and other organism results in the oxidation or release of carbon (the primary component of organic matter) into the atmosphere. Microbes act like tiny soil cows, grazing on organic matter and breathing out CO_2. They convert the carbon from sugars, carbohydrates and amino acids in organic matter to energy and CO_2, a byproduct of the metabolic reaction called oxidation.

Although in the short term tillage increases the numbers of microbes by giving them more oxygen, in the long term, excessive tillage can reduce biological activity and diversity. Soil organic matter is the food source, the fuel for the soil food web. Continually oxidizing soil organic matter diminishes the food source, if it is not replaced.

Burning off soil organic matter creates a domino effect; less food for soil organisms, who then do not produce the sticky substances and long hair like strands of fungal hyphae that knit the soil together into clumps called aggregates. Soil with fewer aggregates has less pore space with less water holding capacity, oxygen and ability to drain. All of these components affect plant growth.

Balancing Tillage with Organic Matter Inputs

While no-tillage agriculture is increasingly popular and has many advantages, it’s not realistic for all situations, especially for new growers. Remember tillage is not all bad. Good tillage regimes provide aeration, a good seed bed, and, most importantly for organic producers, knock back weed pressure.

NATIONAL ORGANIC STANDARDS FOR COMPOST AND MANURE

Raw animal manure must be composted unless it is:

- applied to land used for crops not intended for human consumption.
- incorporated into soil not less than 120 days prior to the harvest of a product whose edible portion has direct contact with the soil.
- incorporated not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil [3].

Many growers like to think of soil organic matter as their savings account. As they build up their soils, they are putting money into their savings account. When they till the soil or grow a crop, they may draw down the account. It is important to keep putting money (organic matter) back in, otherwise the soil and the grower might go broke.

Adding Organic Matter with Compost and Manure

Adding compost and manure to soil can increase your organic matter content. For example, in an 11 year study in Vermont, 20 tons per acre per year of dairy manure (14% dry matter) was able to maintain organic matter levels at 5.3% in a conventionally tilled corn silage field [16]. When they added 30 tons per acre per year, soil organic matter levels increased to 5.5%. In another study, adding 5,200 pounds of dry matter per year maintained soil organic matter (SOM) levels in conventional corn. With no manure additions, SOM decreased by almost 20% in 11 years [16].

Planting Cover Crops to Increase Soil Organic Matter

Cover crops are planted to provide a cover for the soil, grown between orchard rows, or in fields between cropping seasons, but are not harvested. They are grown as a cover, primarily as a biological soil conservation tool, to prevent soil erosion by wind and/or water; but they foster multiple benefits. They are planted before and after the main designated cash crop in a rotation. Cover crops are used as a ground cover or mulch, green manure, nurse crop or a smother crop [13].

Some of the commonly used non-legume cover crops are listed below. Most of these are grasses, which are good for scavenging nitrogen (recovering residual N); preventing erosion; building up soil organic matter; and suppressing weeds. Classified as winter annuals, perennials, biennials and summer annuals, grasses typically have dense masses of fibrous roots that improve the soil structure and stimulate soil microorganisms, which aggregate soil particles. The fine roots of grasses also bind soil crumbs directly [13].

Annual ryegrass. A reliable performer, it can be grown all over the United States where there is moisture, grows quickly, holds soils well, and is a good scavenger of nitrogen. Cutting the ryegrass will increase dry matter and can improve overwintering, if there has been significant fall growth..

Cereal rye. A winter annual, rye is the hardiest of the cereals and may be seeded later in the fall than the others and still gives good soil protection, dry matter, and N scavenging. It grows all over the United States. It is a good weed suppressor, by both shading weeds and releasing allelopathic compounds

NATIONAL ORGANIC STANDARDS FOR COMPOST

Composted plant and animal material must be produced through a process which:

- established an initial C:N ratio of between 25:1 and 40:1; and
- maintained a temperature of between 131 F and 170 F for three days using an in-vessel or static aerated pile system; or
- maintained a temperature of between 131 F and 170 F for 15 days using a windrow composting system, during which period the materials must be turned a minimum of five times [3].

which discourage seeds from germinating. A favorite for rolling down or mowing in spring and seeding soybean into the mulch. The advantage of grasses such as rye as cover crops include low seed costs and quick fall ground cover establishment, vigorous growth, and good winter survivability. The cultivated variety 'Aroostook' rye does well in the Northeast; it is winter hardy, produces significant biomass and will flower earlier than other varieties. In most places 'bin run' rye without a specific variety stated is available and less expensive.

Triticale. A winter annual, Triticale is a cross between wheat and rye, planted and established like wheat or rye. Often grown as a forage; it provides fall and winter cover like rye. Its biomass production and growth rate in spring are less than rye and greater than wheat.

Winter Barley. A winter annual, winter barley grows well in dry or light soils and in poor soils that need to be rebuilt. Barley will tolerate moderately alkaline conditions, but does poorly in acidic soils with pH below 6.0. It out-competes many weeds well by competing for soil moisture.

Oats. A summer annual, oats are low-cost and perform reliably. They can be planted as a nurse crop as a bi-culture in combination with hairy vetch or other winter annual legumes or perennial legumes. The oats will establish quickly in the fall and then winter kills in Zone 6-7 and colder. They like cool, wet weather and produce prodigious biomass. They also compete well with weeds. If planted as a companion crop with legumes, oats may out-compete the legumes if planted too early (August). Wait until September to use oats as a companion crop with legumes such as Austrian winter peas and hairy vetch or other legumes. Oats can also be planted in the spring before a late summer crop. Oats may be prone to lodging in nitrogen-rich soil.

Winter Wheat. Wheat has nearly all the benefits of the other cereal cover crops, yet can double as a cash crop. It has less potential to become a weed than other cereals. It is slower than barley to mature in spring. Wheat is a heavy nitrogen and water user in the spring.

See *Managing Cover Crops Profitably* [14] for more details.

Species	Seeding Rate/ A	Date	Winter-hardy
Rye	1 - 1.5 bu (mix)	Early Aug-Early Nov	Very
	2 - 3 bu (alone)		
Triticale	1 - 1.5 bu (mix)	Early Aug-Oct	Most are very
	2 - 3 bu (alone)		
Wheat	1 - 1.5 bu (mix)	Sept - Oct	Most are very
	2 - 3 bu (alone)		
Oats	1.5 - 2 bu (mix)	July-late Sept	No
	3 - 4 bu (alone)		
Annual ryegrass	5 - 10 lbs (mix)	Aug - Sept	Variety and planting date dependent
	10 - 15 lbs. (alone)		

Cover crop rates and seeding dates.

From Penn State Extension Crop *Management Group*

Cereal rye or 'rye' a winter hardy cover crop and prolific producer of organic matter.

From *Using Cover Crops Profitably.*

Of the eighteen elements needed by plants, only four-- nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) are commonly deficient in soils in Pennsylvania when soil is maintained at the optimum pH level for crops. Of those, N is the most frequently deficient. Deficiencies of other nutrients such as sulfur (S), zinc (Zn), boron (B) and manganese (Mn) can occur, but they most often occur in regions with highly weathered soils such as the southern states or the African subcontinent, and areas with very high rainfall, such as the Pacific Northwest [2].

It is critical that we manage soils for levels that meet, but do not exceed, crop needs. The law of limiting factors was first described by Justus von Liebig (1803-1873) who analyzed plant samples that led him to propose the law. This law states that plant growth is proportional to the amount available of the most limiting nutrient. For example, if I provide nitrogen sufficient to produce 70 bushels of wheat, but only phosphorus for 50 bushels of wheat, I will only get 50 bushels of wheat [12]. However, also beware of applying excessive nutrients. Too many nutrients not only make an environmental hazard, but can also create negative interactions with insect pests, plant diseases, and weeds; or even become toxic to plants at very high levels.

First Step -- Soil Test!

Soil testing is important. Under-applying retards plant growth and will reduce your production. Over-application is not only expensive; it's also an environmental hazard. This holds true for organic nutrient sources as well as synthetic fertilizers. Just because you are using organic sources such as compost and manure does NOT mean that you should merely apply as much compost or manure as is readily available. On a farm in Southeastern Pennsylvania, where mushroom compost is plentiful, one new farmer raised his soil phosphorus from low to highly excessive levels in just one year by applying a load of mushroom compost to two acres. Excess phosphorus and nitrogen can move into water sources causing algal blooms reducing water oxygen to toxic anoxic levels.

N, a very important nutrient and one that is frequently deficient, is NOT included directly in most soil tests. Nearly all of the nitrogen in soil is not in forms that are available to plants, and the N that is in forms that are available to plants – nitrate, ammonium, and certain free amino acids – fluctuate rapidly and widely throughout the season. A heavy rain can leach the nitrate out in a matter of hours or cause large quantities of N to escape to the atmosphere as nitrous oxide, an important greenhouse gas. Since N is so leaky, and levels of available N forms can change so quickly, it is not included directly in most soil tests.

Soil organic matter content is an indirect assessment of soil N. Most labs include organic matter automatically or at least as an option on soil tests. Soil organic matter levels can be interpreted into a rough estimate of the amount of plant-available N. The amount of nitrogen that will be available within a given season can be estimated from the soil organic matter. Depending on the season's temperature and moisture, microbes can be expected to release between 20 and 60 lbs of plant-available N from each % of organic matter in the soil [17]. Microbes will make more N available in warm moist soils and less in cooler or drier soils.

If you don't know whether organic matter is automatically included in your soil test, ask. If organic matter is an optional test, be sure to check the box and pay the extra fee to find out what your soil's organic matter levels are.

How to Read a Soil Test

Every soil test looks a little different, but in general, there will be a graph that gives you a quick summary of how your soil is doing. Start there.

Soil tests provide the levels of P, K, Mg, and pH in soil. If a Penn State soil test has bars that reach all the way across into “Exceeds Crop Needs,” (vegetables) or “Above Optimum” (agronomic crops) the soil has too many nutrients, which will encourage weed growth and contaminate the water supply. If bars are in the below optimum zone, there are not enough nutrients to support the next crop.

There will also be a series of recommendations. For phosphorus and potassium the recommendations are based on the amount of soluble nutrients available in the soil. For nitrogen (not tested directly because it is continually changing from one form to another in the soil) recommendations are based on the amount of nitrogen needed to attain optimal production in average soil. If your soil has high levels of organic matter, less will be needed. If this is your first soil test follow the recommendations as a best guess. Over time, as you build your soils, the trends in the soil tests from year to year rather than the exact recommendation become more important. Are you maintaining, increasing or decreasing your phosphorus and potassium? Are you increasing your organic matter.

Many soil testing labs have a home gardener as well as commercial vegetable, fruit or agronomic soil testing options. Make sure you use the commercial option. Recommendations for home gardeners often do not include more detailed information and can be hard to interpret for organic growers.

Soil pH and Lime

Although, strictly speaking, soil pH is not a plant nutrient, maintaining soil at the optimum pH for your crop is essential to ensuring the crop can access sufficient quantities of soil nutrients. For example, iron deficiency is a common problem in blueberries; however, the soil is rarely deficient in iron. Most often, the pH is simply too high for the blueberries to access enough iron.

Soils in PA tend toward being too acidic for producing most crops. The carbonates in lime neutralize acidity and the calcium and magnesium in lime are essential plant nutrients. There are different types of lime. The most commonly used are calcitic and dolomitic lime. Other forms, such as hydrated lime or quick lime, can be caustic or expensive.

Not all limes provide equivalent soil neutralizing. Look at the CCE-- Calcium Carbonate Equivalent -- to find out how much neutralizing capacity a given lime might have. It is required by law that all limes have their CCE on their labels. For example, lime with a CCE of 50 only has 50% of the liming capability of calcitic lime (the baseline). So you have to use twice as much. Dolomitic lime can actually have more than 100% of the CCE and so you would have to use less than your recommendation. The fineness of lime is also important. The smaller the particles the more surface area there is to react with the soil. Fall is an excellent time to apply lime for it to react with the soil and neutralize acidity before the next crop is grown.
See Penn State’s Soil Acidity and Aglime factsheet for more details [15].

Your Organic Nutrient Choices—**Cover crops, manures, composts, and fertilizers.**

When it comes to building and maintaining soil fertility, farmers have many choices. Those choices fall into 3 broad categories: cover crops, manure and manure-based composts, and commercial fertilizers. Organic nutrient sources vary in their cost, which nutrients they contain, the relative concentrations of those nutrients, and the availability of those nutrients to subsequent crops.

Legume Cover Crops for Nitrogen

Legumes, like peas, beans and clovers, are great organic nitrogen sources. Legumes have a symbiotic relationship with soil bacteria called rhizobia. The rhizobia use the carbohydrate energy they receive from the plant to split the bonds of atmospheric N and convert it into nitrate and ammonium, forms of N that plants can use. There are several legume cover crop options available to farmers in the Northeast. Pick one that meets the N needs of the cash crop to follow and the niche available in the rotation.

Red clover is a common, perennial leguminous cover crop. It is known for being winter hardy in Pennsylvania as well as easy and economical to plant. It can be broadcast and then disked in or broadcast in the early spring or late fall before a frost. The freeze thaw of a frost cycle will work the seed into the ground and it will sprout later. Red clover is slow to establish. Plant clover at 10 lbs/A to receive 50-170 pounds of N per acre. Don't plant it in fields that have heavy weed pressure or for early season nitrogen in an annual rotation. Since red clover is a perennial, plow it in to terminate it – mowing or rolling/ crimping does not kill red clover.

Hairy vetch is winter annual nitrogen-fixing powerhouse. It generally produces the most biomass, fixes the most N, and has the lowest C:N ratio of legume cover crops grown in Pennsylvania (10:1). However if it is large it may smother out under heavy snow. The low C:N ratio and high N production means vetch commonly supplies up to 200 lbs of N to the next crop. (Remember that 200 lbs is based on how much plant material there is. If it does not grow well the N will be little.) Hairy vetch must be established at 20-30 lbs. seed/acre in late summer the year prior to cash crop establishment. In PA this is usually August 1 to September 15, or 6 weeks prior to the first expected frost. Planting too early or too late often results in the vetch dying over the winter. Vetch puts on the most biomass and fixes the most N between mid-April and late-May. Because it is a winter annual, vetch may be terminated by plowing at any time in the spring, or by rolling or mowing when the vetch is in full flower.

Peas are a good choice for a spring cover crop, or a winter annual cover crop in zone 6 south. Peas planted at 60-65 lbs/A. early in the season (end of March) produce up to 2.8 tons of dry matter and 166 pounds of nitrogen. Assuming 40% availability, 66 lb/A of the peas' N is available, enough for many crops.

Crimson clover, like hairy vetch is another winter annual option. A moderate N producer, if planted at 18-20 lb/A in August

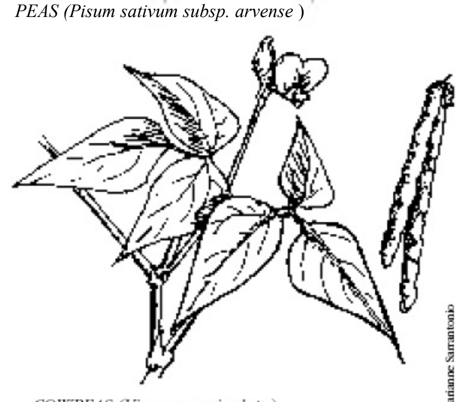
Legume Cover crop rates and seeding dates.

From Penn State Extension Crop Management Group

Crop	Seeding Rate	Seeding Date
Austrian Winter Pea	40 – 80 lbs	Aug – Sept
Hairy Vetch	15 – 20 lbs	Aug – Sept
Crimson Clover	10 – 15 lbs	Aug – mid Sept
Red Clover	8 – 12 lbs	July – mid Sept

HAIRY VETCH (*Vicia villosa, Roth.*)

PEAS (*Pisum sativum subsp. arvense*)



COWPEAS (*Vigna unguiculata*)

Marianne Sarrantonio

or September, crimson clover will produce 70-130 lb/A, 50 lbs available [18]. Crimson clover does not reliably over winter north of zone 6. To terminate crimson clover in the spring, it can be mowed or rolled/crimped at full bloom (usually early to mid-May) or plowed in.

Cowpeas are a summer annual legume that can provide a good quick green manure for farmers who have an available summer niche. Over-seeded in broccoli or other spring crops at 70 lb/A, they will grow quickly after spring crop harvest contributing up to 300 lb N/A to the system by late summer, although 130 lb/A available N is more typical [18]. Cowpeas break down quickly and allow for establishment of a fine seedbed in time for establishing many fall or overwintering crops.

Table 1. Nutrient Composition of Dairy Manure

Manure Type	Total Nitrogen N	Ammonium NH_4-N	Phosphorus P_2O_5	Potassium K_2O
Lot-scraped manure (lb/ton)	10	3	6	9
range	(3 to 20)	(2 to 15)	(0.6 to 13)	(2 to 20)
Liquid manure slurry (lb/1,000 gal)	22	9	14	21
range	(8 to 50)	(4 to 13)	(0.2 to 38)	(0.7 to 50)
Anaerobic lagoon sludge* (lb/1,000 gail)	15	6	22	8
range	(3 to 42)	(1 to 12)	(2 to 64)	(2 to 20)
Anaerobic lagoon liquid (lb/acre-inch)	137	88	77	195
range	(17 to 268)	(22 to 130)	(10 to 233)	(13 to 571)

Source: Biological & Agricultural Engineering Department, North Carolina State University, 1980 to 1990.
*No manure solids removed before lagoon input

Table 2. Fertility Composition Variation in Manures

Source	N (%)	P (%)	K (%)	Application Rate to apply 100 lbs available N/A	Phosphorous in 100 lb N/ A application rate	Potassium in 100 lb N/ A application rate
Fresh Cattle Manure	0.3	0.2	0.3	40 tons/acre	120 lbs P/acre	200 lbs K/acre
Fresh Horse* Manure	0.3	0.2	0.5	33.3 tons/acre	100 lbs P/acre	333 lbs K/acre
Fresh Poultry Manure (75% moisture)	1.5	1	0.5	6.7 tons/acre	133 lbs P/acre	67 lbs K/acre
Poultry Manure (dry, 15% moisture)	6	4	3	1.7 tons/acre	133 lbs P/acre	100 lbs K/acre

*Assuming 50% availability

Calculated with values from *Using Organic Nutrient Sources* [20].

Manure for Soil Fertility

Manure is a highly variable nutrient source. The amounts of nutrients in manure varies by the animal it came from, what it ate, how it's been stored, and how long it's been stored [Table 1]. For example, poultry manure generally has more N than dairy manure and fresh manure has more N than stored manure. Further, the way the manure is applied (broadcast, injected, plowed in) impacts the proportion of nutrients that are lost and the amount left for the crop. If you plan to use manure have it tested to find out what nutrients it contains and in which proportions.

Manure does not provide nutrients in the proportions in which plants use them. In general, if you apply manure to meet plant N needs, you're applying excessive P and K. To avoid building up excessive levels of P and K in your soils, use manure to meet your P and K needs and balance out your N needs with a legume cover crop. To calculate how much manure to apply to meet your P and K needs, see *Using Organic Nutrient Sources* [20].

Table 3. Fertility Composition Variation in Composts

Source	N (%)	P (%)	K (%)	Amount needed for 100 lbs. available* N/A	Phosphorous in 100 lb N/ A application rate	Potassium in 100 lb N/ A application rate
Compost (low fertility)	1.5	0.5	1	16.7 tons/A	166.7 lbs P/A	333 lbs K/A
Compost (high fertility)	3.5	1	2	7.1 tons/ A	142.9 lbs P/A	285.7 lbs K/A
Mushroom compost (low fertility)	0.4	5.7	0.5	62.5 tons/A	7125 lbs P/ A	625 lbs K/A
Mushroom compost (high fertility)	0.7	6.2	1.5	35.7 tons/A	4428.6 lbs P/A	1071.4 lbs K/ A

*Assumes 20% availability

Calculated with values from *Using Organic Nutrient Sources* [20].

Composts for Phosphorous and Slow-release Fertility

Compost is humified organic matter produced by controlled, accelerated decomposition. During the composting process, microorganisms convert raw materials such as manure, straw, leaves, and food waste into stabile organic matter. To foster this accelerated decomposition process, farmers must monitor and maintain the moisture and temperature of the pile, often covering the pile to conserve moisture or turning the pile to mix the raw materials and add air. There is even more variability among composts in the amounts of nutrients they provide than there is among legumes and the amounts of nitrogen they provide. In general composts are good sources of phosphorus and potassium, especially if they're manure-based. Conversely, composts contain very little available nitrogen. Most of the nitrogen in composts is in stable organic forms.

Table 4. Fertility Provided by Common Commercial Organic Fertilizers							
Source	N (%)	P (%)	K (%)	Recommended Application Rate	N-P-K in Rate		
					N lb/acre	*P lb/acre*	*K lb/acre*
Fertrell Liquid Fish Emulsion, 4-1-1	4	1	1	1-2 gal/ 200 gal*	45 to 90	11 t0 22	11 to 22
Fertrell Blue N, 5-1-1	5	1	1	500 lb/A	25	5	5
Bloodmeal	12	0	0	100 lb/A	12	0	0
Bonemeal	3.5	18	0	1000 lb/A	35	180	0
McGeary 5-3-4	5	3	4	400 lb/ A	20	12	16
McGeary 2-3-4	2	3	4	450 lb/A	9	13.5	18
*Assuming 1" water/acre application rate							

Calculated with values from Using Organic Nutrient Sources [20].

To use compost as a fertility source, **have the compost tested** by an agricultural or environmental lab to find out what nutrients (and in which proportions) your compost contains. When applying compost for soil fertility, apply only as much compost as you need to meet your soil's P or K needs. Do not apply enough to meet the next crop's N needs, as that much compost would contain levels of P that far exceed plant needs and are could pollute nearby surface waters. To calculate how much compost to apply to meet your P and K needs, see *Using Organic Nutrient Sources* [20].

Commercial Fertilizers

For Certified Organic growers commercial fertilizers are usually the most expensive option for meeting your crop's fertility needs. The number of commercially available organic fertilizers has increased dramatically in recent decades. Many, like fish emulsion, blood meal, feather meal, and bone meal, are by-products of the meat-packing industry. Others, like alfalfa meal, soybean meal and others, are by-products of the feed industry. Commercial fertilizers are a good option to meet a specific nutrient deficiency quickly. These short-term benefits come at a cost. Unlike cover crops, compost, and manure they generally do not come with the added benefits of a large organic matter input that provides longer-term slow-release soil fertility. To find a commercial organic fertilizer that could meet your short term soil fertility needs and calculate how much you'll need to apply, please see *Using Organic Nutrient Sources* [20].

Conventional growers can more easily attain commercial fertilizers. See your state's commercial vegetable guide for additional details.

Building Fertile Biologically Active Soils

As a new grower you not only want to supply the nutrients your crop needs this year, but also slowly build your soils and enhance your soil health. Soils with high organic matter not only increase the structure of your soil, but also store more nutrients and maintain large, diverse biological communities. For example, soil scientists assume about 20 lbs of plant available nitrogen per acre per year for each percent of organic matter in the soil. A soil with six percent organic matter would likely provide sufficient nitrogen for most vegetable crops.

Soil biota not only enhance the physical structure of the soil (pg 2) they also play critical roles in nutrient availability and cycling. For example, a type of mutalistic fungus called mycorrhizae colonize plant roots and grow networks of thin strands, acting like extensions of the plant roots. In exchange for sugars and carbohydrates from the plants, the mycorrihizae scavenge nutrients, like phosphorus from deep in the soil and provide them to plants. Other types of biota such as microscopic worms called nematodes and tiny soil insects, feed on soil bacteria and fungi. As they graze the soil flora they release nitrogen in forms more available to plants, acting like tiny soil cows whose 'manure' is fertilizing the soil.

All of the subtleties of building and maintaining diverse, active biological communities are not yet understood. But, two principles generally hold true: provide abundant, diverse food sources for soil biota and enhance their habitat (less tillage/ better soil structure). Including perennials and cover crops in your rotation are good ways to provide stable food sources for soil biota. Reducing tillage, including long rotations with perennials, and increasing soil organic matter and structure tend to enhance biological diversity.

References

1. Duiker, S.W., *Effects of Soil Compaction*. 2004, Penn State, College of Agricultural Sciences, University Park, PA.
2. Magdoff, F. and H.M. van Es, *Building Soils for Better Crops*. Vol. 10. 2009: Sustainable Agriculture Research and Education Program.
3. PCO, *The Pennsylvania Certified Organic Guide*. 2005, Centre Hall, PA: Pennsylvania Certified Organic.
4. Gugino, B.K., et al., *Soil Health Training Manual*, Cornell, Editor. 2007: Ithaca, NY.
5. Doran, J.W., et al., *Defining Soil Quality for a Sustainable Environment.* SSSA Special Publication: Soil Science Society of America Journal, 1994. 49.
6. USDA. *Soil Quality Concepts*. Available from http://soils.usda.gov/sqi/concepts/concepts.html.
7. Russell, E., *Soil Texture Descriptions*, in *Teaching Organic Farming and Gardening*, A. Miles and M. Brown, Editors. 2005, University of California: Santa Cruz.
8. FAO, *Farmer Field Schools The Soil System*. 2007.
9. Brady, N.C. and R.R. Weil, *The Nature and Properties of Soils*. 11th edition. 1996: Upper Saddle River, NJ: Prentice Hall.
10. Duiker, S.W., *Diagnosing soil compaction using a penetrometer (soil compaction tester):* Agronomy Facts 63. 2002, Penn State College of Agriculture and Extension: University Park.
11. Duiker, S.W., *Avoiding Soil Compaction*. 2004, Penn State College of Agricultural Sciences, University Park, PA.
12. Miles, A. and M. Brown, *Teaching Organic Farming and Gardening: Resources for Instructors*. 2007, Santa Cruz, CA: University of California Farm and Garden.
13. Wilson, D., *Cover Crops for the Northeast - terminology, benefits, selection*, in *The Rodale Institute*. 2008.
14. Clark, A., ed. *Managing Cover Crops Profitably*. Sustainable Agriculture Network Handbook Series. 2007, Sustainable Agriculture Network: Beltsville, MD. pg 67.
15. Beegle, E. and D.D. Lingenfelter, *Soil Acidity and Aglime*, 1995, Penn State College of Agricultural Sciences, University Park, PA.
16. Magdoff, F. and R.R. Weil, *Soil Organic Matter in Sustainable Agriculture*. 2005, Boca Raton, FL: CRC Press, LLC.
17. Gaskell, M., R. Smith, J. Mitchell, S. T. Koike, C. Fouche, T. Hartz, W. Horwath, L. Jackson. *Soil Fertility Management for Organic Crops*. Organic Vegetable Production in California Series, #7249, 2006. University of California, Division of Agriculture and Natural Resources. Available from: http://anrcatalog.ucdavis.edu
18. Sarrantonio, M. *Northeast Cover Crop Handbook.* 1994, Emmaus, PA: Rodale Institute
19. Zublena, J.P., J. C. Barker, D.P. Wesen. *Soil Facts: Using Dairy Manure as a Fertilizer Source*. 1994, North Carolina Cooperative Extension Service. Available from: http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-28/AG-439-28.pdf (accessed June 27, 2011).
20. Sanchez, E.S. and T.L. Richard. *Using Organic Nutrient Sources*, 2009, Penn State College of Agricultural Sciences, University Park, PA

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, and Alison Grantham, Beginning Farmer Associate, Penn State Extension. Reviewed by Doug Beegle, Penn State Crop and Soil Science, Charlie White, Penn State Extension and Lee Rinehart, Pennsylvania Certified Organic.
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Determining Nutrient Applications for Organic Vegetables – Basic Calculations

In an organic production system, we generally focus on building our soils instead of on directly feeding our crops. This can be done using a number of sources including compost, manures and cover crops. In addition to fulfilling the requirements of a systems plan for certified organic production, and providing slow release of the nutrients plants need, organic matter additions increase soil aggregates, water holding capacity and other soil qualities important for healthy plant growth [1].

However, nutrients supplied from organic materials are supplied slowly over time. We are actually feeding soil organisms that release these nutrients. The rate that nutrients are released depends on the number of soil organisms, the quality of the material they eat, soil temperature, moisture and more. Because availability is dependent on a number of factors including biological activity, we can only make an estimate of nutrient availability – but an estimate is better than a guess.

In order for us to calculate how many nutrients to apply to our fields, we need to know how much is being released from the soil organic matter and the organic inputs we have applied in the past. This requires testing the amount of nitrogen, phosphorus, and potassium in what we apply, testing our soil, doing some basic calculations and keeping a nutrient budget. See *Using Organic Nutrient Sources*, and *Deciding which Organic Nutrients to Use and How Much to Apply* <http://extension.psu.edu/vegetable-fruit/fact-sheets>. These tools are easy to use, requiring a little bit of basic math, your soil test and your compost or manure test. If you have not tested your inputs, the procedure below will get you close. Remember – an estimate is just an estimate.

STEP 1: Use Table 1.0 below to calculate your nutrient needs based on tables 1.1-1.4

Line 1. Recommendations based on Nutrient Needs: Vegetable specific recommendations based on research are given in the *Commercial Vegetable Production Recommendations* [2] available at < http://pubs.cas.psu.edu/FreePubs/pdfs/agrs028.pdf >.

Line 2. Recommendations based on Soil Test: See your soil test report. Note that nitrogen recommendations on your soil test from Penn State are not based on soil nitrogen levels because available soil nitrogen levels fluctuate greatly day to day and even hour to hour. Nitrogen recommendations on your soil test are from average recommendations (Line 1).

Line 3a. Soil Organic Matter: Most recommendations account for some organic matter N for average soil OM levels. However, if organic matter has been increased a larger credit should be taken. Calculate this additional credit as 20 pounds per acre of nitrogen (0.5 lb/1,000 sq. ft.) for each percent OM over 2%. For example, if a soil that has 3% organic matter you could expect this to provide 20 pounds of additional OM nitrogen per acre [1]. This is the credit that would be entered in the table. Phosphorus and Potassium from soil organic matter will be reflected in the soil test values and should not be included here. [1].

Line 3b. Manure Nitrogen: Use Table 1.1 to find the amount of nitrogen available from manure applied in the last 2 years. We are assuming that the manure you applied will be slowly available over three years. In year one, 50% of the nitrogen is released; in year two and three, 50% of what is left. If there is not an application rate similar to what you used in the chart, multiply the percent of each nutrient times the pounds you applied to give you the total amount of nutrients you applied per acre. Then divide by four to get the amount available 1 or 2 years after it was applied. Remember, according to national organic standards, any raw manure must be applied 120 days before harvest of a vegetable in direct contact with the soil may not be advisable to use on a crop destined to be eaten raw for food safety. Make sure to check with your certifier.

Line 3b. Manure Phosphorus & Potassium: If a soil test was taken after this manure application, the phosphorus and potassium from the manure will be reflected in the soil test values and should not be included as a credit here. If no soil test has been take since these previous applications, a credit for the P and K applied minus what the crops removed should be taken. If no information is available on actual crop P and K removal, an average of 25 lb P2O5 per acre and 100 lb K_2O per acre can be used for removal. Use Table 1.2 to calculate estimated values if no soil tests are available.

Line 3c. Compost Nitrogen: Use Table 1.1 to find the amount of nutrients available from compost applied in the previous two years. This table assumes that 15% of the nitrogen contained in the compost is available the year after it was applied and 10% of what is left the following year. This will vary depending on how mature the compost is. If the compost is less mature, more will tend to be available in the first year. If you are certified organic, any compost you bring from off the farm and apply must be approved by your certifier. Compost you make on the farm must follow the processes outlined in the national organic standard and approved by your certifier.

Line 3c. Compost Phosphorus & Potassium: If a soil test was taken after this compost application, the phosphorus and potassium from the compost will be reflected in the soil test values and should not be included as a credit here. If no soil test has been take since these previous applications, a credit for the P and K applied minus what the crops removed should be taken. If no information is available on actual crop P and K removal an average of 25 lb P2O5 per acre and 100 lb K_2O per acre can be used for removal from vegetables. Use Table 1.2 to calculate estimated values if no soil tests are available.

Line 3d. Cover Crop: Use Table 1.3 to find the amount of nitrogen that may be available in the season following a legume cover crop. For a more accurate estimate see handout *Calculating Nitrogen Availability from Your Legume Cover Crop* available from Penn State Cooperative Extension – Northampton County < tdupont@psu.edu >. There will be no P or K credit for cover crops because they do not add P or K, they just hold it in the soil.

Line 3e. Leguminous Crop: Use Table 1.4 to find the amount of nitrogen that may be available in the season following a previous crop of alfalfa, soybean or clover hay. There will be no P or K credit for leguminous crops because they do not add P or K, they just hold it in the soil.

Table 1.0 Calculating Nutrient Credits and Needs[a]

Step	**Nitrogen (N) lbs/A**	**Phosphate (P_20_5) lbs/A**	**Potash (K_2O) lbs/A**
1. Total crop nutrient needs (from Vegetable Guide)	*only needed if you don't have a soil test		
2. Recommendations based on soil test			
3. Credits			
a. Soil organic matter			
b. Manure			
c. Compost			
d. Prior legume cover crop			
e. Prior leguminous crop			
4. Total credits (add a. +b. + c. +d +e.)			
5. Additional needed (2. - 4.)			

[a] From Table 8.2.1 *Organic Cole Crop Production* NYS IPM Publication No. 134 [1].

Table 1.1 Available Nitrogen from Compost and Manure[a] (Note values vary – test your compost/manure)

Sources	Total Nitrogen[b]		Nitrogen Available (lbs/year)[c]							
	%	lb/ton	100 lbs (wheel barrow)/A		2,000 lbs (1 ton pickup)/A		80[f] tons (1"/ acre)		Other[d]	
			Year 1	Year 2-3	Year 1	Year 2-3	Year 1	Year 2-3	Year 1	Year 2-3
Compost										
Availability Factor [c]			*.15*	*.1*	*.15*	*.1*	*.15*	*.1*	*.15*	*.1*
Compost[a,b]	1.5-3	30-60	.2 - .5	.15 - .3	4.5-9	3.0-6.0	360-720	240-480		
Mushroom Compost[a,b]	0.4-0.7	8-14	.06-.07	.06-.07	1.2-2.1	.8 - 1.4	96-168	64-112		
Manure										
Availability Factor [c]			*.5*	*.25*	*.5*	*.25*	*.5*	*.25*	*.5*	*.25*
Horse Manure[c,d]	0.6	12	.3	.15	6	3	480	240		
Cattle Manure[c d]	0.25	5	.13	.07	2.5	1.3	200	104		
Sheep Manure[c,d]	1.15	23	.6	.3	12	6	920	460		
Swine Manure[c,d]	0.2	4	.1	.05	2	1	160	80		
Poultry Broiler[c d]	4	79	2	1	40	20	3160	1580		
Poultry Layer[c,d]	2	37	1	.5	19	9	1480	740		
Tested Compost/Manure										

[a] From *Using Organic Nutrient Sources* Table 3 [3].

[b] The values in this table are typical or "book" values for the different materials. The analysis of these materials varies significantly therefore the materials you plan to apply should be analyzed and the values in the table should only be used as a ***crude*** replacement for actual analysis.

Below the calculations that are used in this table and that should be used with an actual analysis are explained.

[c] **Total N --** Manure and compost analysis maybe given on an analysis report as either % or lb/ton use either of these to determine how much total N is in the material being applied.

(In the examples below assume the Manure Analysis = 12 lb N/ton or 0.6% N. Note that in these examples, they are all the same manure and same application rates just in different units)

- If the material is managed as tons/A and the analysis is in lb N/ton simply multiply tons/A x lb N/ton to get the total N applied/A
  Example*: Typical Application rate 20 ton manure/A x 12 lb N/ton = 240 lb total N/A*

- If the material is managed as tons/A but the analysis is in %N, multiply the %N as a fraction x 2000 to get the lb N/ton and then multiply this by the tons/A to get the total N applied/A.

***Example**: Typical Application rate 20 ton manure/A x 2000 lb/ton x 0.006 N = 240 lb total N/A*

- If the material is managed as lb/area and the analysis is in lb N/ton, first divide the lb N/ton by 2000 to lb N/lb material then multiply this times the number of pounds of material to be spread to get the total N applied to that area.
  ***Example**: Typical Application rate 138 lb manure spread over 10 ft x 15 ft area*
  (12 lb N/ton ÷ 2000 lb manure /ton) x 138 lb manure ÷ (10 ft x 15 ft))= 0.0056 lb N/ft^2
  0.0056 lb N/ft^2x 43,560 ft^2/A = 240 lb total N/A
  -OR- 0.0056 lb N/ft2x 1000 ft2 = 5.6 lb total N/1000 ft2
  -OR- 0.0056 lb N/ft2x 100 ft2 = 0.56 lb total N/100 ft2

- If the material is managed as lb/area and the analysis is in %N, first multiply the % as a fraction times the number of pounds of material to be spread. to get the total N applied to that area.
  ***Example**: Typical Application rate 138 lb manure spread over 10 ft x 15 ft area*
  (0.006 N x x 138 lb manure ÷ (10 ft x 15 ft))= 0.0056 lb N/ft^2
  0.0056 lb N/ft^2x 43,560 ft^2/A = 240 lb total N/A
  -OR- 0.0056 lb N/ft2x 1000 ft^2 = 5.6 lb total N/1000 ft^2
  -OR- 0.0056 lb N/ft2x 100 ft^2 = 0.56 lb total N/100 ft^2

c **Available N --** To determine the amount of this total N that will be available in the current year, multiply the amount of total N applied times the appropriate availability factor from the table above. Note that there are different factors for compost and manure, and there are different factors for the year the manure is spread (Year 1) and the second and third year after application (Year 2-3). Do this calculation for the current year and each of the last 2 years that manure or compost was applied.

***Example**:*
<u>Current Year Availability(Year 1)</u>
Total N = 240 lb N/A x 0.5= 120 lb N/A available in the year spread (Year 1)
Total N = 5.6 lb N/ 1000 ft^2 x 0.5= 2.8 lb N/1000 ft^2 available in the year spread (Year 1)
Total N = 0.56 lb N/ 100 ft^2 x 0.5= 0.28 lb N/100 ft^2 available in the year spread (Year 1)
<u>Previous Year Availability (Year 2 & 3)</u>
Total N = 240 lb N/A x 0.25= 60 lb N/A available each of the previous 2 years (Year 2&3)
Total N = 5.6 lb N/ 1000 ft^2 x 0.25= 1.4 lb N/1000 ft^2 available each of the previous 2 years (Year 2&3)
Total N = 0.56 lb N/ 100 ft^2 x 0.25= 0.14 lb N/100 ft^2 available each of the previous 2 years (Year 2&3)

Area adjustment -- Recommendation will most likely be in lb/A, lb/1000 ft^2 or lb/100ft^2. To adjust for these areas use the following conversions.

- If the application rate is in lb/area ft^2 divide the lb N applied by the area ft^2 then then multiply this by the area used in the recommendations.
  - If the recommendation is in lb/A, multiply this by 43,560 ft^2 = lb Avail. N/A.
  - If the recommendation is in lb/1000ft^2 multiply this by 1000 ft^2 = lb Avail. N/1000 ft^2.
  - If the recommendation is in lb/100 ft^2 multiply this by 100 ft^2 = lb Avail. N/100 ft^2.

- If the application rate is in lb/A but the recommendation is in some other units, divide the lb N applied by the area in an acre 43,560 ft^2 then then multiply this by the area used in the recommendations.
  - If the recommendation is in lb/1000ft^2 multiply this by 1000 ft^2 = lb Avail. N/1000 ft^2.
  - If the recommendation is in lb/100 ft^2 multiply this by 100 ft^2 = lb Avail. N/100 ft^2.

The sum of the values calculated above for the previous 2 years will be entered into table 1 as the “Manure Credit”

The amount of available N for year 1 will be used to determine an appropriate application rate in Table 2.

[d] From the *Penn State Agronomy Guide* Table 1.2-13 [4].

[e] Note that at this rate, very large amount of N is applied. This could exceed crop requirements which should be avoided. Even if the available N calculations show these very high rates to be acceptable, there is concern with the total N loading and future consequences.

Table 1.2 Available Phosphorus and Potassium from Compost and Manure the Year after Application (Year 2)

Sources	Nutrients				Available Nutrients lb/A							
	P_2O_5		K_2O		2,000 lbs (1 ton pickup)/A		5 ton/A		80 tons (1"/ A)[f]		Other	
	%	lb/ton	%	lb/ton	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O		
Compost[a,c]	0.5-1	10-20	1-2	20-40	0[d,e]	0[d,e]	50	50	1175	2300		
Mushroom Compost[a,c]	5.7-6.2	114-124	0.5-1.5	10-30	94	0[d,e]	570	0[d,e]	9495	1500		
Horse Manure[b,c, g]	.25	5	.45	9	0[d,e]	0[d,e]	0[d,e]	0[d,e]	375	620		
Cattle Manure[b,c]	0.2	4	.25	5	0[d,e]	0[d,e]	0[d,e]	0[d,e]	295	300		
Sheep Manure[b,c]	0.4	8	1	20	0 [d,e]	0[d,e]	15	0[d,e]	615	1500		
Poultry Broiler[b,c,h]	3.1	62	2.1	42	37	0[d,e]	285	110	4935	3260		
Poultry Layer[b,c,h]	2.8	55	1.6	30	31	0[d,e]	250	55	4375	2380		
Compost/manure tested												

[a] From *Using Organic Nutrient Sources* Table 3 [3].

[b] From the *Penn State Agronomy Guide* Table 1.2-13 [4].

[c] For P & K we assume that 100% of the nutrient is available the year it is applied. However each crop may not use all of the P & K you apply. If you took a soil test after your last crop the remaining P & K will be reflected in your soil test. Use the numbers from your soil test. If you did not you may use the numbers above or calculate a more specific value below.

[d] For P multiply %P by the amount you applied (ie for poultry manure broiler at 3.1% P multiply .031 x 2000 lb = 62 lb P) and then subtract the amount of P your last crop used. On average vegetables use 25 lbs of P per year. IE. (62 lb of P applied – 25 lb used by the vegetable crop = 37 lb of P available for the next crop. P removal rates vary by crop. In some cases, the P applied will be less than removal as indicated by the "0" in the table. For more specific values see Nutrient Removal Rates for Vegetables [5].

[e]For K multiply K by the amount you applied (ie for poultry manure broiler at 2.1% K multiply 0.021 x 2000 lb = 42 lb P applied). Then subtract the amount of K your last crop used. On average vegetables use 100 lbs of K per year. IE. (42 lb K applied – 100 lb K used = -58 lb K) you most likely don't have any K left in this scenario as indicated by the "0" in the table. K removal rates vary by crop. For more specific values see Nutrient Removal Rates for Vegetables [5].

[f] Note that at this rate, very large excesses of P and K are applied. For example, one application of mushroom compost at the 1" /A rate would supply enough P for 380 years of typical vegetable crop removal (9495 / 25 = 380 yrs)! A large excess, such as this, can saturate the ability of the soil to hold phosphorus and result in significant potential for soluble P loss to the environment.

[g] No bedding included in this number.
[h] Includes litter in analysis figure.

Table 1.3 Available Nitrogen from a Previous Legume Cover Crop [a]

Legume Cover Crop	Dry Matter (lb/A/yr)	Total N[c] (lb/A)		Available N (lb/A)[b]		Available N (lb/1,000 sq ft) [b]	
		low	high	low	high	low	high
Berseem Clover	6,000-10,000	75	220	30	88	0.7	2.0
Cowpeas	2,500-4,500	100	150	40	60	0.9	1.4
Crimson Clover	3,500-5,500	70	130	28	52	0.6	1.2
Field Pea	4,000-5,000	90	150	36	60	0.8	1.4
Hairy Vetch	2,300-5,000	90	200	36	80	0.8	1.8
Medics	1,500-4,000	50	120	20	48	0.5	1.1
Red Clover	2,000-5,000	70	150	28	60	0.6	1.4
Subterranean Clover	3,000-8,500	75	200	30	80	0.7	1.8
Sweet Clover	3,000-5,000	90	170	36	68	0.8	1.6
White Clover	2,000-6,000	80	200	32	80	0.7	1.8
Wooly Pod Vetch	4,000-8,000	100	250	40	100	0.9	2.3

[a] Summarized from *Managing Cover Crops Profitably* [6].

[b] We are assuming that 40% of the nitrogen in the cover crop is available.

[c] The amount of nitrogen depends on the amount of cover crop that you grow. If you have a poor stand or the cover crop only grows to half its potential height then use the low range numbers. If you are plowing your cover crop in late in the spring or there is a lot of biomass there use the high range. Remember, really poor stands mean no contribution at all.

Table 1.4 Available Nitrogen Contributed from Previous Leguminous Crop[a]

Previous crop[b]	Percent Stand	High productivity fields	Moderate productivity fields	Low productivity fields
First year after alfalfa	Nitrogen Credit (lbs/A)			
	>50%	120	110	80
	25-49%	80	70	60
	<25%	40	40	40
First year after clover or trefoil hay	Nitrogen Credit (lbs/A)			
	>50%	90	80	60
	25-49%	60	60	50
	<25%	40	40	40
First year after soybeans harvested for grain	1 lb N/bu soybeans - avg yield in PA = 46 bu/A 2009			

[a] From the *Penn State Agronomy Guide* Table 1.2-7 [4].

[b] When a previous legume crop is checked on the Penn State soil test information sheet, the residual nitrogen for the following year is calculated and given on the report. This credit should be deducted from the N recommendation given on the soil test report.

STEP 2: Use Table 2.0 to Calculate Your Nutrient Applications based on Tables 2.1-2.4

Line 1. This is from Table 1.0 line 5.

Line 2. Choose possible sources from Tables 2.1 – 2.3. The first choice will generally be to utilize materials already on the farm e.g. manures or composts or other readily available nearby sources. Many organic sources are multiple nutrient sources. An important consideration with these sources is that the relative amounts of the different nutrients in these materials may not match up with the nutrient requirements of crops. For example, if most manures or composts are applied to meet the available N requirements of a crop, excess P and K will usually be applied. If possible, the best approach is to apply these multi-nutrient sources at a rate that does not apply a significant excess of any nutrient. Realize that this will result in less than adequate amounts of the other nutrients. In order to avoid over application of P & K, ***choose your planned rate for manure or manure based compost on PHOSPHORUS needed.***

Line 3-5. Select single nutrient sources or sources with a high proportion of the needed nutrient to supplement manure or compost to meet the crop requirements. It is a good idea to write down the rates for several sources and figure out the cost per pound or per application of nutrient. Circle the source(s) you plan to use and cross out more expensive or unavailable options.
The necessary calculations follow:

[a] Calculate the rate per acre or per 1000 sq ft of each source to meet the nutrient need. To do this divide the nutrient need by the available N, P_2O_5, or K_2O in the material from the actual analysis and calculated availability as shown with table 1.1 or if you do not have an analysis, use table 1.1. for N or the total P or K from table 1.2 Alternatively, find the amount of nutrient required at the top of tables 2.1-2.3 for N, P, and K respectively and then read the rate of the desired material from the table.

[b] Select a practical planned rate per acre or 1000 sq ft for this material that is less than or equal to the calculated rate.

[c] Multiply the available N, P_2O_5, or K_2O in the material calculated from your analysis or from table 1.1 and Table 1.2 times this planned rate to determine the amount of N, P_2O_5, or K_2O applied per acre or 1000 sq ft at the planned rate.

[d] Calculate the balance after the planned application of each source by subtracting the nutrient applied in previous step from the Nutrients Needed or the balance from the previous application.

[e] Ideally the balance after the last material is applied should be 0, indicating that the nutrient needs have been met exactly. When using organic sources, this is rarely the case because they contain multiple nutrients in a variety of ratios that do not always match the ratio of nutrient required by crops. In general, it is highly recommended that N not be significantly over applied. Over application of P can represent an environmental threat. If P is significantly over applied you should assess the possibility that P could be transported from the site to nearby water primarily by erosion or runoff. If this is likely, excess P should not be applied. The Pennsylvania P Index (http://pubs.cas.psu.edu/freepubs/pdfs/UC180.pdf) is a tool that can help make this assessment. If P transport from the field is not a concern, excess P applied in one year can be used in following years. However, this build up should be considered in the long term planning and repeated applications of excess P should be avoided. Excess K is not an environmental concern but can be a crop quality concern that should be considered.

Table 2.0 Calculating Nutrient Applications

Nutrients Needed								
				Nitrogen (N)	Phosphate (P_20_5)	Potash (K_2O)		
1. Additional Needed Nutrients - lbs/A (Table 1.0 line 5)								
OR								
1. Additional Needed Nutrients - lbs/1000 sq ft (Table 1.0 line 5 ÷ 43.5)								
Nutrients to Apply								
	Nutrient Source	[a]Calc. rate/Acre or 1000 sq ft.	[b]Planned rate/Acre or 1000 sq ft.	[c] Nitrogen (N) lbs/A or 1000 sq ft.	[d] Phosphate (P_20_5) lbs/A or 1000 sq ft.	[e] Potash (K_2O) lbs/A or 1000 sq ft.	$/acre or 1000 sq ft.	
2. Source 1								
[4]Balance after Source 1 is applied								
3. Source 2 (alternative A)								Compare price of alternatives A,B,C
Source 2 (alternative B)								
Source 2 (alternative C)								
[d]Balance after Source 2 is applied								
4. Source 3 (alternative A)								Compare price of alternatives A,B,C
Source 3 (alternative B)								
Source 3 (alternative C)								
[d]Balance after Source 3 is applied								

2.1. Available NITROGEN from Organic Fertilizer[a] (per ACRE)

Sources	Total Nutrients (lb nutrient/lb material)[b]			Target lbs of N per acre				
				20	40	60	80	100
	N-P_2O_5-K_2O			Provided by lbs of fertilizer below				
Compost [b,c]	**0.015-.03**	0.005-0.01	0.01-0.02	8889 - 4447	17780 - 8887	26667 - 13333	35553-17780	44447 - 22220
Fertrell Blue N 5-1-1	**0.05**	0.01	0.01	400	800	1200	1600	2000
Fish Meal	**0.09**	0.06	0	222	444	667	889	1111
McGeary 8-1-1	**0.08**	0.01	0.01	250	500	750	1000	1250
McGeary 2-3-4	**0.02**	0.03	0.04	1000	2000	3000	4000	5000
McGeary 6-0-4	**0.06**	0	0.04	333	666	1000	1333	1667
Blood Meal	**0.13**	0	0	154	308	462	615	769
Feather Meal[d]	**0.15**	0.01	0.01	133	267	400	533	667
Alfalfa Meal	**0.025**	0.02	0.02	800	1600	2400	3200	4000
Horse Manure (Fresh)[e]	**0.006**	0.0025	0.005	6667	10000	20000	26667	33334
Cattle Manure (Fresh) [e]	**0.003**	0.0015	0.0025	13000	27000	40000	53000	67000
Poultry Manure Broiler[e]	**0.04**	0.03	0.02	1000	2000	3000	4000	5000
Other[f]								

[a] Adapted from *Using Organic Nutrient Sources* and *Organic Cole Crop Production* calculations of nutrient needs [1, 3].

[b] The percentage of plant available nutrients is highly variable. Averages are used here. Testing for compost and manures is recommended.

[c] For compost, average values for nutrient content are used. First multiply lb nitrogen/ lb material x amount applied, i.e., for 1.5% N or 0.015 lb N/lb compost (0.015 x 2,000 lbs = 30 lbs N applied). Then multiply by the percent available. For compost, we assume 15% N available for plant use the year we apply it, i.e. (30 lbs N applied x 0.15 = 15 lb N available in the year we apply it).

[d] Adjusted for slow availability over a year and a half. Mulitiply lbs applied by %N by .75 in the year after application.

[e] 50% of nitrogen is available during year of application. Actual nutrients available are highly variable due to amount of bedding included and animal diet. Testing of your manure source is recommended. Un-composted manure must be used on fields with crops not to be consumed by humans or incorporated into soil a minimum of 90 days before harvest, provided the product does not touch the soil and 120 days before harvest if the product does contact the soil for certified organic production.

[F] **To calculate the application rate for a nutrient source not listed in the table, or based on your compost/manure test:**

Target rate _____lbs of N/A ÷ ____lbs N/ lb material x availability factor (0.5 for manure, 0.15 for compost) = _______lbs of fertilizer/A to apply.

2.2 Available PHOSPHORUS from Organic Fertilizer[a] (per ACRE)

Sources	Total Nutrients (lb nutrient/ lb material)[b] N-P_2O_5-K_2O			Target lbs of P_2O_5 per acre 20	40	60	80	100
				Provided by lbs of fertilizer below				
Compost	0.015-.033	**0.005-0.01**	0.01-0.02	4000 -2000	8000 -4000	12000 - 6000	16000 - 8000	20000 - 10000
Bonemeal	0.04	**0.15**	0	133	267	400	533	667
Rock Phosphate[b]	0	**0.3**	0	270	530	800	1100	1300
McGeary Organics 2-3-4	0.02	**0.03**	0.04	667	1333	2000	2667	3333
Fishmeal	0.09	**0.06**	0	333	667	1000	1333	1667
Horse Manure (Fresh-no bedding)	0.006	**0.0025**	0.005	8000	16000	24000	32000	40000
Cattle Manure	0.003	**0.0015**	0.0025	13333	26667	40000	53333	66667
Poultry Manure Broiler	0.04	**0.03**	0.02	670	1300	2000	2700	3300
Other[c]								

[a] Adapted from *Using Organic Nutrient Sources* and *Organic Cole Crop Production* calculations of nutrient needs [1, 3].
[b] Application rate adjusted for very slow release rate (x4).
[c]To calculate the application rate for a nutrient source not listed in the table, or based on your compost/manure test:

Target rate _____lbs of P_2O_5/A ÷ ____lbs P_2O_5/ lb material = _______lbs of fertilizer/A to apply.

2.3 Available POTASSIUM from Organic Fertilizer[a] (per ACRE)

Sources	Nutrients (lb nutrient/lb material)[b]			Target lbs of K_2O per Acre 20	40	60	80	100
	$N-P_2O_5-K_2O$			Provided by lbs of fertilizer below				
Compost	0.015-.03	0.005-0.01	**0.01-0.02**	2000 - 1000	4000 - 2000	6000 - 3000	8000 - 4000	10000 - 5000
Sul-Po-Mag	0	0	**0.22**	91	182	273	364	455
Wood Ash[c]	0	0	**0.05**	400	800	1200	1600	2000
Greensand[b]	0	0	**0.03**	8000	16000	24000	32000	40000
Potassium Sulfate	0	0	**0.5**	40	80	120	160	200
McGeary 8-1-1	0.08	0.01	**0.01**	2000	4000	6000	8000	10000
McGeary 2-3-4	0.02	0.03	**0.04**	500	1000	1500	2000	2500
McGeary 6-0-4	0.06	0	**0.04**	500	1000	1500	2000	2500
Alfalfa Meal	0.025	0.02	**0.02**	1000	2000	3000	4000	5000
Horse Manure [d] (Fresh-no bedding)	0.006	0.0025	**0.005**	4000	8000	12000	16000	20000
Cattle Manure	0.003	0.0015	**0.0025**	8000	16000	24000	32000	40000
Poultry Manure [d] Broiler	0.04	0.03	**0.02**	1000	2000	3000	4000	5000
Other[d]								

[a] Adapted from *Using Organic Nutrient Sources* and *Organic Cole Crop Production* calculations of nutrient needs [1, 3].

[b] Application rates for this material are adapted due to their slow release rates. Adapted by Vernon Grubinger from the University of Maine soil testing lab [1].

[c] Also raises pH.

[d] From the *Penn State Agronomy Guide* Table 1.2-13 [4].

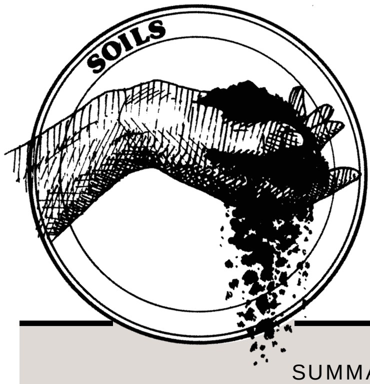
[e] To calculate the application rate for a nutrient source not listed in the table, or based on your compost/manure test:

Target rate _____lbs of K_2O/A ÷ ____lbs K_2O/ lb material = _______lbs of fertilizer/A to apply.

References

1. Abawi, G.S., et al., *2010 Production Guide for Organic Cole Crops*, A. Seaman, Editor. 2010, Cornell University, New York State Department of Agriculture and Markets, Integrated Pest Managment.
2. Orzolek, M.D., et al., *Commercial Vegetable Production Recommendations* 2010, University Park, PA: Penn State Cooperative Extension.
3. Sanchez, E. and T.L. Richard, *Using Organic Nutrient Sources*. 2009, The Pennsylvania State University: University Park, PA.
4. Rudisill, A., *Penn State Agronomy Guide 2009-1010*. 2010, State College, PA: Pennsylvania College of Agricultural Sciences
5. Osmond, D.L. and J. Kang, *Nutrient Removal by Crops in North Carolina*, in *North Carolina Cooperative Extension*. 2008, http://www.soil.ncsu.edu/publications/Soilfacts/ag-439-16W.pdf.
6. Clark, A., ed. *Managing Cover Crops Profitably*. Sustainable Agriculture Network Handbook Series. 2007, Sustainable Agriculture Network: Beltsville, MD. pg 67.

Prepared by Tianna DuPont, Sustainable Agriculture Educator, Northampton and Lehigh Counties. Edited by Doug Beegle, PSU Crop and Soil Sciences; Elsa Sanchez, PSU Horticultural Systems Management. *Last updated - January 2012.*



Soil acidity and aglime

SUMMARY

- Soil pH indicates the acidic level of a soil. A pH less than 7.0 indicates an acid soil.
- Soil acidification is a natural process that is increased by normal production practices, particularly the use of nitrogen fertilizer and manure.
- High levels of soil acidity (low soil pH) can reduce root growth, reduce nutrient availability, affect crop protectant activity.
- For most agronomic crops the soil pH should be between 6.0 and 7.0.
- A soil test determines the soil pH which indicates whether liming is required.
- The soil test also gives the exchangeable acidity of the soil. This along with optimal pH for crop growth, determines how much limestone is required to neutralize the acidity.
- Most aglime materials are calcium and/or magnesium carbonates. Burnt lime, hydrated lime, and some by-product materials are also used. Calcium sulfate (gypsum) and magnesium sulfate (Epsom salts) are not liming materials.
- Lime quality is based upon the neutralizing ability as determined by its calcium carbonate equivalent (CCE) and by the speed of reaction as determined by its fineness. Calcium and magnesium content and moisture level are also important.
- Lime quality information is required by Pennsylvania law to be on the label of all aglime materials.
- Soil test lime recommendations are usually given as an amount of CCE per acre. The actual amount of material required to meet the recommendation will vary depending on actual CCE, moisture content, and depth of incorporation.
- Actual cost of liming materials is compared on the basis of an equal amount of CCE.
- Liming materials should be mixed with the soil where possible.
- Even finely ground liming materials require several months to react. Apply aglime well in advance of acid-sensitive crops to allow time for it to neutralize soil acidity.

Soil acidity is among the important environmental factors which can influence plant growth, and can seriously limit crop production. Therefore, liming acid soils is basic to good soil and crop management. A sound liming program will increase soil productivity and, possibly more important under current conditions, increase efficiency of other crop production inputs such as fertilizers and crop protectants.

DEFINITION AND CAUSES OF SOIL ACIDITY

Acid soils are defined as any soil that has a pH of less than 7.0 (neutral). Acidity is due to hydrogen (H^+) ion concentrations in the soil. The higher the H^+ concentration, the lower the pH. It is also important to note that a one-unit change in pH equals a ten-fold change in acidity, therefore, small changes in pH can dramatically effect the lime requirement of that soil. Soil acidity is comprised of two components: active acidity and exchangeable (reserve) acidity. Active acidity is the concentration of H^+ ion in the solution phase of the soil and is measured by pH but is not a measure of the total *soil* acidity. The soil pH is a general indicator of whether aglime is needed to reduce the acidity. The exchangeable acidity refers to the amount of H^+ ions on cation exchange sites of negatively charged clay and organic matter fractions of the soil. Soil exchangeable acidity determines the amount of aglime necessary to increase the soil pH. Therefore, soil test reports show both soil pH and exchangeable acidity and a lime recommendation based on this total acidity, as well as other factors.

Initially, each type of soil has a certain level of acidity depending upon its composition, native vegetation, and rainfall amounts, however, various factors over time cause changes in soil pH. Leaching, erosion, and crop uptake of basic cations (calcium, Ca^{2+}; magnesium, Mg^{2+}; potassium, K^+), decay of plant residues, and plant root exudates are all means by which the soil acidity is increased. However, a common source of acidity comes from H^+ ions that are released when high levels of aluminum (Al^{3+}) in the soil react with water molecules. Acid residuals also occur from certain fertilizers.

Nitrogen sources that supply ammonium or react in the soil to produce ammonium nitrogen (e.g., ammonium nitrate, urea fertilizers, and animal manures) form acid and tend to increase soil acidity. With these reactions occurring, it is necessary to neutralize the acidity by adding lime to

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the soil. The approximate pounds of calcium carbonate ($CaCO_3$) needed to *neutralize* the acidifying effects of one pound of nitrogen are as follows:

*3 pound*s for ammonium nitrate (NH_4NO_3), urea (NH_2-CO-NH_2), nitrogen solutions/UAN (urea+NH_4NO_3+water), and anhydrous ammonium (NH_3)

5.3 pounds for diammonium phosphate (DAP), [$(NH_4)_2HPO_4$]

7 pounds for ammonium sulfate [$(NH_4)_2SO_4$], monoammonium phosphate (MAP), [$NH_4H_2PO_4$], and ammonium polyphosphate (APP)

EFFECTS OF SOIL ACIDITY ON CROP PRODUCTION

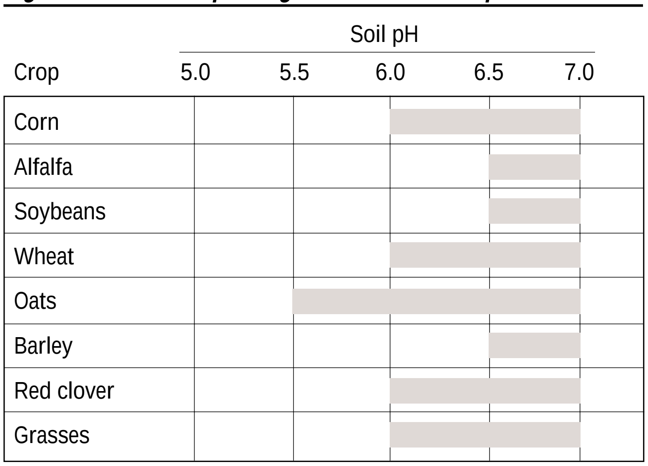
For most agronomic crops, a soil pH of 6.0 to 7.0 is ideal for crop growth, however, the pH tolerance range for various crop species can vary (Figure 1). For example, legumes, as a group, and barley respond better to a pH range between 6.5 and 7.0, whereas oats can tolerate a pH of 5.5.

However, liming soil to maintain an optimal pH improves crop production in the long run. For example, perennial legumes will respond with higher yields and stand longevity. Other management factors also need to be considered, such as soil pH effects on herbicides. Soil pH below 6.0 causes reduced activity of triazine herbicides, whereas a pH greater than 7.0 can cause carryover problems with other types of herbicides. Although liming provides some plant-nutrient value (Ca^{2+} or Mg^{2+}), its greatest benefit to plant growth is by counteracting the negative effects of soil acidity which can cause several of the following problems.

Soluble metal toxicity

As the pH decreases below 5.5, the availability of aluminum and manganese (Mn) increase and may reach a point of toxicity to the plant. Excess Al^{3+} in the soil solution interferes with root growth and function, as well as restricting plant uptake of certain nutrients, namely, Ca^{2+} and Mg^{2+}. Liming acid soils reduces the activity of Al and Mn.

Figure 1. Favorable pH ranges for common crops.



Effect on phosphorus availability

Acid soils causes P to form insoluble compounds with aluminum and iron. Liming soils with low pH "dissolves" these insoluble compounds and allows P to be more available for plant uptake. However, liming soil to points beyond 7.0 causes P to form complexes with Ca or Mg, therefore, it's best to maintain the soil pH between 5.5 and 6.8 to curb these problems (see Figure 2).

Micronutrient availability

The availability of micronutrients increases as soil pH decreases, except for molybdenum. Since micronutrients are needed by the plants in only minute quantities, plant toxicity in addition to other detrimental effects occur with excess amounts. Refer to Figure 2 for relationship between pH and nutrient availability.

Soil organisms

Microorganisms associated with nitrification (conversion of NH_4^+ to NO_3^-), require a certain soil pH range to function efficiently. Since these organisms require large amounts of Ca to perform the conversion, a pH of 5.5 to 6.5 is necessary for Ca to be available. Also, the activity of bacteria (*Rhizobia* species) which are responsible for nitrogen fixation in legume crops decreases when the pH drops below 6.0. In addition to less N being produced by organisms for crop utilization, microbes responsible for the breakdown of crop residues and soil organic matter are also affected by acid soils. Other microorganisms vary in their tolerance to soil pH.

Soil physical condition

Liming fine-textured soils improves the structure, and that has several positive attributes including reduced soil crusting, better emergence of small-seeded crops, and less power required for tillage operations.

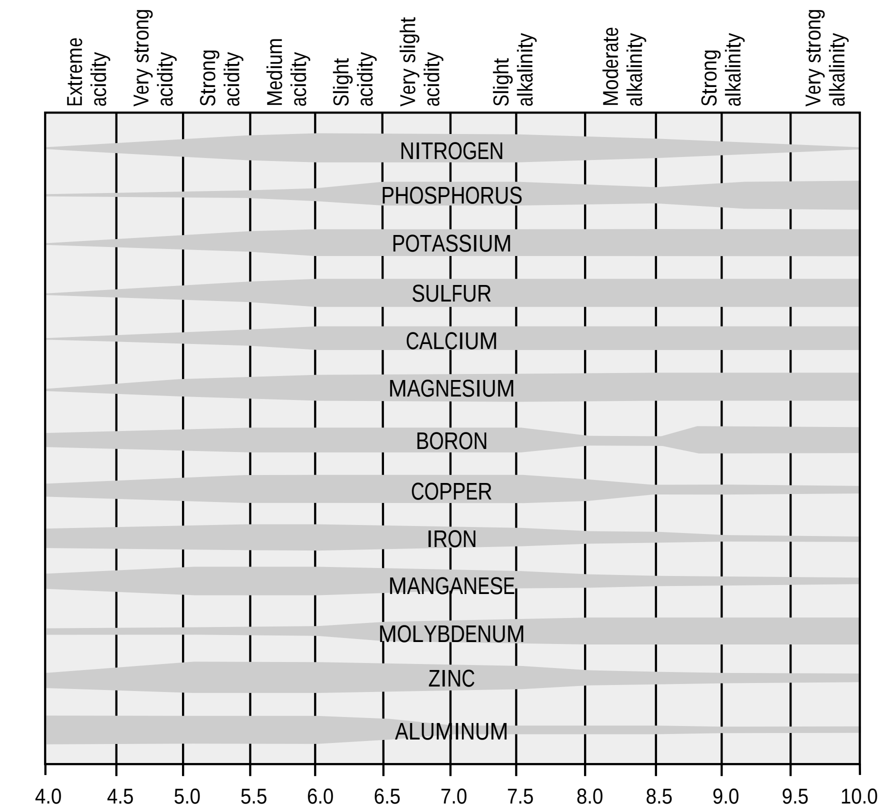
Disease

Soil acidity can have an influence on certain plant pathogens (disease-causing organisms). However, pathogens vary in their tolerance to soil acidity, so no soil pH range can be recommended. Therefore, proper identification of the problem is necessary before any management tactic is utilized.

SOIL SAMPLING

A soil test performed by a reliable laboratory provides a good estimate of the fertility status of a field. Proper soil sampling is an important first step in the testing process and should be done according to the directions with the sampling kit. Sampling techniques differ, however, for no-till situations. If the area has been in no-till corn management for two years or more, it is advisable to measure the pH of the soil surface. Since surface applications of nitrogen fertilizers and manure may acidify the upper soil layer, decreasing herbicide effectiveness and other chemical reactions, an analysis of acidity within the upper two inches of soil is necessary. Collect several representative cores less than two inches deep from the no-till area and

Figure 2. How soil pH affects availability of plant nutrients and aluminum.



mix thoroughly in a clean bucket. Remove a sample and measure the acidity with a simple accurate colorimetric field pH kit. If the pH of the surface soil is less than 6.2, take a standard soil sample for laboratory analysis. If the standard sample does not indicate a need for limestone and the surface pH is below 6.2, apply 2,000 pounds of calcium carbonate equivalent material. This amount of aglime should be adequate to neutralize the surface acidity.

AGLIME

A good liming program is based on a soil test that determines the degree of soil acidity and the correct amount of a liming material needed to neutralize that acidity. Once this amount is determined, a liming material must be selected that will economically satisfy the soil test recommendation and result in maximum, efficient production. However, before considering the necessary lime application amounts, an understanding of aglime materials, quality, and associated laws is helpful.

Aglime materials

Aglime is an agricultural liming material capable of neutralizing soil acidity, i.e., increasing soil pH. Common aglime materials and some of their important chemical properties are given in Table 1. By far the most common aglimes used in Pennsylvania (approximately 99 percent) are ground calcitic and dolomitic limestone. While they do supply essential calcium and magnesium in the process of liming, it is the carbonate, oxide, or hydroxide part of these compounds that neutralizes soil acidity. Materials such as calcium sulfate (gypsum) or magnesium sulfate (Epsom salts) are not liming materials, even though they contain calcium and magnesium, because they are not capable of neutralizing soil acidity.

Table 1. Common aglime materials.

Material	Chemical formula	% CCE
Pure calcitic limestone	$CaCO_3$	100
Dolomitic limestone	$(Ca, Mg)CO_3$	109
Calcium oxide; lime, burnt, lump, or unslaked lime, quicklime	CaO	179
Calcium hydroxide; hydrated, slaked, or builders' lime	$Ca(OH)_2$	136
Marl and shells	$CaCO_3$	70–90
Slag (various)	$CaSiO_3$	60–90
Industrial by-products	varies	varies

Aglime quality

Not all limestone is the same. The quality of aglime varies significantly and should be an important consideration in aglime management. Four factors are most important in assessing aglime quality; chemical purity, speed of reaction, magnesium content, and moisture.

1. Chemical purity

The chemical purity of aglime determines the amount of soil acidity the material can neutralize. Chemical purity is indicated by the material's calcium carbonate equivalent (CCE): the amount of soil acidity the material can neutralize compared to pure calcium carbonate (calcitic limestone, $CaCO_3$). The CCE is given as a percentage: a 100-percent-CCE limestone would be just as effective as pure calcitic limestone in neutralizing value; 90-percent-CCE limestone would be only 90 percent as effective; and a 109-percent-CCE limestone such as a dolomitic limestone would be 109 percent as effective. The calcium carbonate equivalent is given for each of the materials listed in Table 1. Calcium carbonate equivalent indicates only the equivalent neutralizing value of an aglime material; it says nothing about the actual calcium carbonate content of the material. For example, note that pure calcium hydroxide (hydrated or slaked lime) has a CCE of 136 percent but contains no calcium carbonate.

The CCE value of a limestone is obtained directly by dissolving a sample of the material in an acid. However, aglime analysis is often reported in different ways, such as calcium oxide (CaO) and magnesium oxide (MgO) or as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). You can easily calculate the CCE value of an aglime material reported in these ways by using the conversion factors listed in Table 2. Convert the analyses to calcium carbonate and then add them up.

Table 2. Conversion factors for liming materials.

	Ca x 2.50 = $CaCO_3$
	Mg x 4.17 = $CaCO_3$
	CaO x 1.79 = $CaCO_3$
	MgO x 2.50 = $CaCO_3$
	$MgCO_3$ x 1.19 = $CaCO_3$
	$Ca(OH)_2$ x 1.36 = $CaCO_3$
Example:	
	Ca 35% x 2.50 = 87.50%
	Mg 2% x 4.17 = 8.34%
	CCE = 95.84%

Liming materials containing less than 50 percent CCE are mostly of components that do not contribute to the neutralizing capabilities of the material. As compared to an aglime with a higher percentage CCE value, larger amounts would be necessary to reduce soil acidity. The chemical purity of a limestone depends on the geologic formation where the material is quarried or mined and can vary considerably from quarry to quarry or even within a single quarry. This variation is a problem that producers must face in guaranteeing aglime quality.

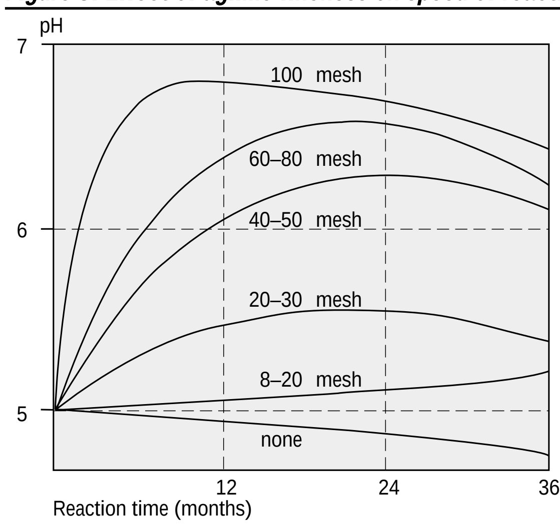
2. Speed of reaction

The speed with which an aglime material reacts with the soil to neutralize acidity and thus increases soil pH is determined by the fineness of the material. The finer the material, the faster it will react because limestone's solubility increases as it is ground finer. Also, limestone affects only a very small volume of soil around each particle, so the finer the material, the greater the total surface area that is available to come into contact with the soil and neutralize it (assuming adequate soil mixing). Aglime should react with the soil as quickly as possible. Generally, aglime should react completely within three years. Quicker reaction may be desirable on rented ground or for shorter-season annual crops.

Aglime fineness is given as the percentage of the material that passes through sieves of specified mesh. Sieve mesh is the number of wires per inch on the sieve. The higher the number, the finer the material that will pass through.

Aglime larger than 20 mesh (about the fineness of table salt/sugar) reacts extremely slowly; little will react within two to three years. The speed of reaction increases to a practical maximum with 100-mesh material. The effect of aglime fineness on speed of reaction is shown clearly in Figure 3.

Figure 3. Effect of aglime fineness on speed of reaction.



In each case illustrated in Figure 3, sufficient aglime was applied to neutralize the soil acidity to raise the soil pH to 7.0. However, only the 100-mesh material came close to achieving that goal. Therefore, it would seem desirable to use only 100-mesh or smaller aglime. However, this decision must be balanced against the high cost of grinding limestone to finer than 100 mesh. A compromise must be reached so that the material is fine enough to be effective agronomically but still economical. A material with at least 95 percent passing through a 20-mesh sieve, 60 percent passing through a 60-mesh sieve, and 50 percent passing through a 100-mesh sieve is generally adequate. Spending extra for a finer-sized liming material would only be recommended in emergency situations where very rapid reaction is required.

3. Calcium and magnesium content

In addition to acid neutralization capabilities, lime also serves as a source of calcium and magnesium. The magnesium content of aglime is important when a soil test indicates a need for magnesium. Magnesium requirements are met most economically by applying an aglime material that contains magnesium.

The magnesium content of aglime varies considerably. Unfortunately, there is no official trade classification of limestone according to its magnesium content. Local classification schemes often create confusion. Therefore, to select the proper aglime material, you should use the actual magnesium analysis rather than a name (e.g., dolomitic lime, high-magnesium lime).

Magnesium soil-test recommendations are usually given in one of the three different ways: as pounds of Mg per acre, or as pounds of MgO per acre, or as pounds of calcium carbonate equivalent per acre with a specific Mg or MgO content. Liming materials must be labeled to indicate their percentage of Mg; however, additional information on percentage of MgO may also appear. When the recommendation and label are in different forms, a simple conversion is required. To convert Mg into MgO, multiply by 1.67; but to convert MgO into Mg, multiply by 0.602.

4. Moisture

The moisture content of an aglime does not directly affect its effectiveness. However, since lime is sold and applied by weight, including water weight, a high moisture content means less actual liming material per ton. When moisture content approaches 10 percent or more, the application rate of aglime per acre should be adjusted to ensure that the required amount of actual liming material is applied to the soil. Use the following formula to make the adjustment or refer to the example calculations section:

$$\frac{\text{soil test recommendation (CCE/A)} \times 100}{100 - \%\ \text{moisture}}$$

THE PENNSYLVANIA LIME LAW

The quality of aglime sold in Pennsylvania is regulated by the state law, Agricultural Liming Materials Rules and Regulations. Since aglime quality cannot be determined by visual inspection, these regulations help to assure farmers (consumers) that they are getting what they pay for. Recently, state lime regulations were changed to keep requirements consistent with laws throughout the northeastern region of the United States. These new labeling requirements will be in full effect by September 1995. The following information is a summary of the new Agricultural Liming Materials Rules and Regulations.

1. Types

Aglime materials must be labeled according to their type (e.g., limestone, hydrated lime, burnt lime, industrial by-products or marl and shells).

2. Elemental calcium and magnesium

Aglime materials must be labeled as to the Total Calcium (Ca) and Total Magnesium (Mg) percentage by weight contained in the product. Oxide and carbonate guarantees may be stated following the elemental guarantee.

3. Fineness

The label must state the classification (fine-sized, medium-sized or coarse-sized materials) of the product and the minimum percentages by weight passing through the US standard 20-, 60-, and 100-mesh sieve. The classification must meet the minimum standards outlined by regulation. (certain special limestone materials for lawn and garden have different quality standards). The following outlines the three groups based on fineness for agronomic liming materials:

Fine-sized materials
- 95% through a 20-mesh sieve
- 60% through a 60-mesh sieve
- 50% through a 100-mesh sieve

Medium-sized materials
- 90% through a 20-mesh sieve
- 50% through a 60-mesh sieve
- 30% through a 100-mesh sieve

Coarse-sized materials
- All liming materials that fail to meet one of the above minimums for fineness.

4. CCE

The label must state the minimum CCE value of the aglime material.

5. Effective neutralizing value (ENV)

The label must state the minimum ENV of the aglime material. [The ENV is a relative value that expresses soil acidity neutralizing capabilities of a liming material and is determined by using the calcium and magnesium oxide content and fineness. ENV is not utilized in Pennsylvania, but it is used by some other states of the region. The term is similar to “effective neutralizing power” (ENP)].

6. Moisture

The label must state the maximum moisture content by weight of the material. A tolerance of 10 percent of the guarantee is set for moisture greater than what is stated on the label.

7. Dry-weight analysis

The guarantees for elemental Ca and Mg, CCE, and ENV must appear on the label under the heading: “Guaranteed Dry Weight Analysis.” If oxides and carbonates are guaranteed they should follow the elemental guarantee.

8. Tolerances

A tolerance of 2 percent of the guarantee is allowed for the guaranteed minimum CCE value and minimum fineness value. All other guarantees are allowed a 10-percent tolerance range.

SOIL TEST AGLIME RECOMMENDATIONS

Liming an acid soil to an optimal range is the initial step in creating favorable soil conditions for productive plant growth. The lime recommendation on the soil test report is based on the amount of exchangeable acidity (or exchangeable H^+) measured by the lime requirement soil test and the optimum soil pH for the crop. For a desired pH of 7.0, the lime requirement can be estimated as follows:

Lime requirement = exchangeable acidity x 1,000

For a desired pH 6.5, the lime requirement is estimated as follows:

If the exchangeable acidity is greater than 4.0, then:
Lime requirement = exchangeable acidity x 840

If the exchangeable acidity is less than 4.0 and the soil pH is still less than 6.5, then:
Lime requirement = 2,000 lb/A

Otherwise, no lime is required.

Soil test recommendations should take into account that aglime quality varies significantly. Most soil test recommendations for aglime are based on 100 percent calcium carbonate equivalent acid neutralizing ability, as well as based on liming an acre-furrow slice approximately seven inches deep. The Penn State aglime recommendations are given as pounds of calcium carbonate equivalent per acre. Thus, you must adjust the recommendation when using an aglime material with a CCE different from 100 percent CCE. The following formula is used to calculate the adjusted amount of an aglime material needed to meet the soil test recommendation:

$$\frac{\text{soil test limestone recommendation}}{\text{CCE of aglime to be used}} \times 100$$

Refer to the example calculations section for a detailed example.

This adjusted recommendation can be calculated from this formula or read directly from Table 3. The Agricultural Analytical Services Laboratory at Penn State includes a copy of this formula and table as part of the recommendations with each soil test

The soil test recommendation assumes that the agliming material meets the minimum standard requirements for fine-sized liming materials specified in the lime law.

If the aglime material will be incorporated with a large volume of soil (i.e., if the plow depth is more than nine inches), the recommendation is adjusted according to the following formula:

$$\frac{\text{Actual plow depth (inches)}}{7} \times \text{Basic requirement lime} = \text{Adjusted lime requirement}$$

or one can use the guidelines that follow:

Plow depth	Adjusted aglime requirement
Less than 9 inches	No adjustment
9 to 11 inches	Basic requirement x 1.5
More than 12 inches	Basic requirement x 1.8

EXAMPLE CALCULATIONS FOR ADJUSTING AGLIME MATERIALS

- Soil test recommendation:
  Limestone — apply 6,000 pounds of calcium carbonate equivalent per acre.

- Information known:
  Calcium carbonate equivalent of aglime material = 90%

  Moisture content of aglime material = 15%

  Incorporate to 10 inches

- Adjusting material to recommended percentage of CCE example:

$$\frac{\text{Soil test limestone recommendation}}{\text{CCE of aglime to be used}} \times 100$$

$$\frac{6{,}000}{90} \times 100 = 6{,}667 \text{ or } 6{,}700 \text{ lb/A of liming material needed}$$

- Moisture adjustment example:

$$\frac{\text{Soil test recommendation (CCE/A) or adjusted material to recommended \%CCE}}{100 - \text{\% moisture}} \times 100$$

$$\frac{6{,}700}{100 - 15} \times 100 = 7{,}882 \text{ or } 7{,}900 \text{ lb/A of liming material needed}$$

- Adjusting for incorporation with large soil volume example:

$$\frac{\text{Actual plow depth (inches)}}{7} \times \text{Basic lime requirement} = \text{Adjusted lime requirement}$$

$$\frac{10}{7} \times 7{,}900 = 11{,}286 \text{ or } 11{,}300 \text{ lb/A of liming material needed}$$

In this example, after all the adjustments were made, a total of 11,300 pounds per acre would be necessary to neutralize the soil acidity. Since the requirement is a large quantity, it would be best to use split-applications at two different time periods approximately six months apart or by tillage operations. Smaller, more frequent applications are suitable for no-till situations. Notice that by incorporating the lime to depth greater than seven inches causes an increase of over 1 1/2-times the original lime requirement. Therefore, be sure that your plow depth is accurate and that overapplication of aglime will not occur.

Table 3. Liming material conversion.

Find your soil test limestone recommendation in the left-hand column and then read across the table on that line until you come to the column headed by the percentage CCE nearest to that of your liming material. The number at that point is the pounds of liming material required to meet the limestone recommendation on your soil test.

Because there is generally little advantage in applying more than 8,000 pounds of CCE per acre in any one application to agricultural land, this table is divided into three sections suggesting how the total liming material required can be split for more efficient use. Separate the applications by six months or at least by tillage operations (see the right-hand column). In no-till, the recommended aglime can be applied in smaller, more frequent applications.

Actual lb/A calcium carbonate equivalent recommended on your soil test	PERCENTAGE CALCIUM CARBONATE EQUIVALENT (% CCE) OF YOUR LIMING MATERIAL												Divide total into the following number of applications
	50	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	
1,000	2,000	1,800	1,700	1,500	1,400	1,300	1,200	1,200	1,100	1,100	1,000	1,000	
2,000	4,000	3,600	3,300	3,100	2,900	2,700	2,500	2,400	2,200	2,100	2,000	1,900	
3,000	6,000	5,500	5,000	4,600	4,300	4,000	3,700	3,500	3,300	3,200	3,000	2,900	
4,000	8,000	7,300	6,700	6,200	5,700	5,300	5,000	4,700	4,400	4,200	4,000	3,800	1
5,000	10,000	9,100	8,300	7,700	7,100	6,700	6,200	5,900	5,600	5,300	5,000	4,800	
6,000	12,000	10,900	10,000	9,200	8,600	8,000	7,500	7,100	6,700	6,300	6,000	5,700	
7,000	14,000	12,700	11,700	10,800	10,000	9,300	8,700	8,200	7,800	7,400	7,000	6,700	
8,000	16,000	14,500	13,300	12,300	11,400	10,700	10,000	9,400	8,900	8,400	8,000	7,600	
9,000	18,000	16,400	15,000	13,800	12,900	12,000	11,200	10,600	10,000	9,500	9,000	8,600	
10,000	20,000	18,200	16,700	15,400	14,300	13,300	12,500	11,800	11,100	10,500	10,000	9,500	
11,000	22,000	20,000	18,300	16,900	15,700	14,700	13,700	12,900	12,200	11,600	11,000	10,500	
12,000	24,000	21,800	20,000	18,500	17,100	16,000	15,000	14,100	13,300	12,600	12,000	11,400	
13,000	26,000	23,600	21,700	20,000	18,600	17,300	16,200	15,300	14,400	13,200	13,000	12,400	2
14,000	28,000	25,500	23,300	21,500	20,000	18,700	17,500	16,500	15,600	14,700	14,000	13,300	
15,000	30,000	27,300	25,000	23,100	21,400	20,000	18,700	17,600	16,700	15,800	15,000	14,300	
16,000	32,000	29,100	26,700	24,600	22,900	21,300	20,000	18,800	17,800	16,800	16,000	15,200	
17,000	34,000	30,900	28,300	26,200	24,300	22,700	21,200	20,000	18,900	17,900	17,000	16,200	
18,000	36,000	32,700	30,000	27,700	25,700	24,000	22.500	21,200	20,000	18,900	18,000	17,100	
19,000	38,000	34,500	31,700	29,200	27,100	25,300	23,700	22,400	21,100	20,000	19,000	18,100	3
20,000	40,000	36,400	33,300	30,800	28,600	26,700	25,000	23,500	22,200	21,100	20,000	19,000	

EXAMPLE CALCULATIONS FOR COMPARING AGLIME MATERIALS

To compare aglime materials, convert the materials to “per ton of CCE” and then compare the total cost per ton of CCE. Keep in mind that the material must meet the minimum fineness requirements. As long as these minimums are met, fineness would not be a major consideration except in an emergency that requires extremely rapid reaction. Following is an example comparing three liming materials:

	Material A	**Material B**	**Material C**
Liming material specifications	CCE: 10% Fineness: 100% through 20 mesh 90% through 60 mesh 80% through 100 mesh Price: $2/ton	CCE: 75% Fineness: 95% through 20 mesh 70% through 60 mesh 50% through 100 mesh Price: $12/ton	CCE: 105% Fineness: 95% through 20 mesh 60% through 60 mesh 50% through 100 mesh Price: $20/ton
	Dealers are required by law to supply the above information.		
Calculations Calculate the actual material required per ton of CCE from the formula given in the previous section. The actual material required for products with a CCE between 50 and 105 percent can be read directly from Table 3, “Liming material conversion.” All calculations may be rounded to the nearest 100 pounds. Formula: Actual material required per ton of CCE $= \frac{2{,}000 \times 100}{\text{CCE}}$ For each of these materials these calculations are as follows:	$\frac{2{,}000 \times 100}{10}$ = 20,000 lbs actually required (10 tons)	$\frac{2{,}000 \times 100}{75}$ = 2,700 lbs actually required (1.35 tons)	$\frac{2{,}000 \times 100}{105}$ = 1,900 lbs actually required (0.95 tons)
Cost per ton of CCE	10 tons x $2/ton = $20.00/ton of CCE	1.35 tons x $12/ton = $16.20/ton of CCE	0.95 tons x $20/ton = $19.00/ton of CCE

In this example, material B would be the best buy.

Prepared by Douglas B. Beegle, professor of agronomy and Dwight D. Lingenfelter, extension assistant.

Agronomy Facts 63

Diagnosing soil compaction using a penetrometer (soil compaction tester)

THE RATIONALE FOR THE PENETROMETER

Soil compaction is a serious concern for farmers in Pennsylvania. Soil compaction can easily reduce crop yields by 10 percent, and can lead to water and soil quality degradation due to increased runoff and soil structure destruction. The continuous consolidation of farms means that herds are growing, more forage is harvested per farm, more manure is being produced, larger equipment is used to spread manure and harvest and transport forages and grain, and the opportunity to tailor field operations to optimum soil conditions for traffic is decreasing. Compaction is therefore an issue that will likely increase in importance in the years to come.

There are two forms of compaction: surface and subsurface. While surface compaction can be partly alleviated with normal tillage operations, subsurface compaction below the normal tillage depth will remain. Fracturing or cutting subsurface compacted soil has, in some cases, resulted in remarkable yield increases. Many Pennsylvania producers suspect they have a subsurface compaction problem, but have no handle on how to measure it. A diagnostic tool to measure the extent and depth of subsurface compaction is a penetrometer, or soil compaction tester. This tool can help producers determine if subsoiling might be beneficial and at what depth the subsoiler should be set. Several companies sell penetrometers that are all based on the same technical specifications of the American Society of Agricultural Engineers. A penetrometer will cost around $200.

A penetrometer consists of a 30-degree circular stainless steel cone with a driving shaft and a pressure gauge (Figures 1a and 1b). The penetrometer usually comes with two cones,

Figure 1a. A penetrometer, or soil compaction tester, has a graded shaft and separate reading scales for each tip. (Figure courtesy of Dickey John)

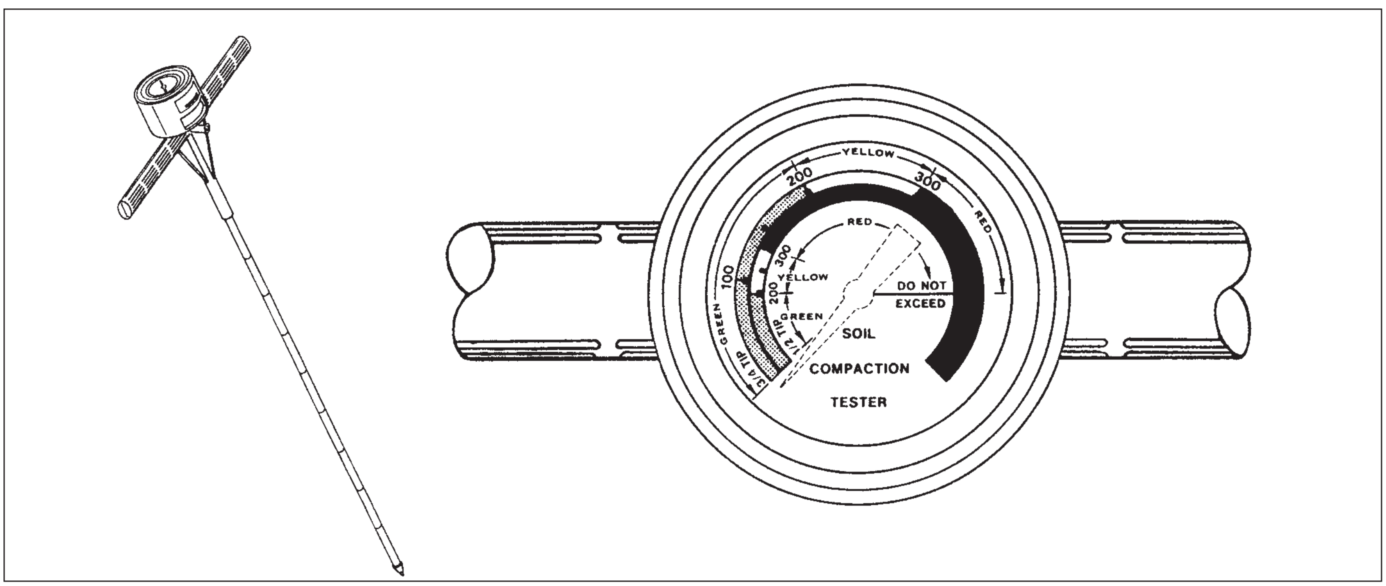


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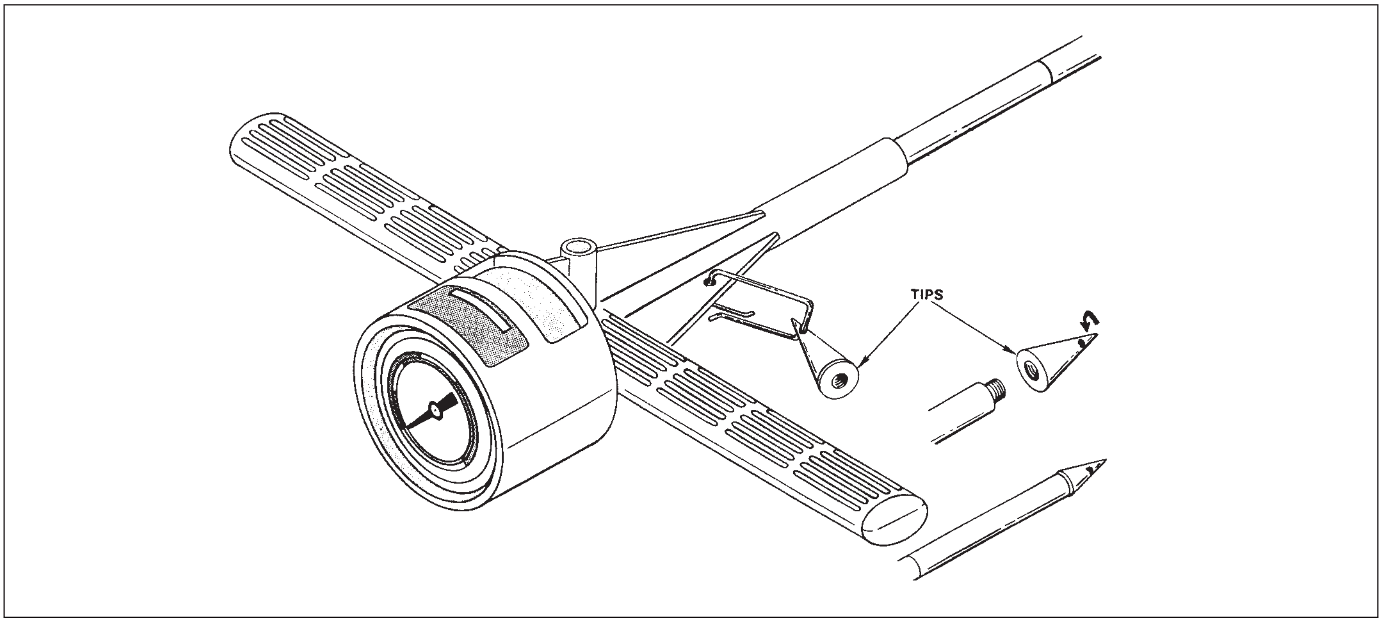
Figure 1b. A penetrometer usually comes with two points (1/2 and 3/4 inch diameter). (Figure courtesy of Dickey John)



one with a base diameter of 0.798 (3/4) inches for soft soils and the other with a base diameter of 0.505 (1/2) inches for hard soils. The tip is slightly wider than the driving shaft to limit friction of the shaft with the soil. The driving shaft is usually graduated every 3 inches to allow the determination of depth of compaction. The pressure gauge indicates pressure in pounds per square inch (be sure to use the appropriate scale for the tip you are using).

The penetrometer is designed to mimic a plant root. Of course, a plant root is living, and much smaller than a penetrometer, so the penetrometer can be expected to have some shortcomings. In studies conducted at the United States Department of Agriculture's Agriculture Research Service (USDA-ARS), root penetration into soil cores packed to different densities was measured and compared to penetrometer readings. Root penetration decreases linearly with penetration resistance, until almost no roots penetrate into soil with a penetration resistance of 300 psi (Figure 2). Much of this research was done with cotton, but it also appears to hold true for other crops. Although the limit of zero root growth may not be exactly at 300 psi, it is certain that root growth will be greatly inhibited at higher penetrometer readings. This is true in both wet and dry soils, and is independent of soil texture. Unfortunately, the penetrometer does not capture pores created by physical or biological forces such as freezing/thawing, wetting/drying, earthworm burrowing, and root channeling. Plant roots will find and grow through these spaces in the soil if they are present.

HOW TO USE THE PENETROMETER

The readings taken with the penetrometer are called the cone index. The readings should be taken when the whole profile is at field capacity (approximately 24 hours after a soaking rain). The best time of the year for the compaction measurement is the spring because the whole profile has usually been thoroughly moistened during the winter. If the soil is too wet (muddy), compaction could be underestimated because the soil acts as a liquid. If the soil is too dry, compaction could be overestimated because roots will be able to penetrate the soil when it dampens. The idea behind using the penetrometer at field capacity is that this is the best-case scenario for roots. Hopefully, the soil will be at field capacity at various times during the growing season. During these periods, roots will be able to penetrate soil that has low penetration resistance. Penetration resistance will increase when the soil dries out, and root growth can then be expected to be limited. However, when the moisture content of the soil increases again, penetration resistance will decrease, and root growth will resume.

The penetrometer rod should be driven in the soil at a rate of approximately 1 inch per second. As you push the penetrometer into the soil, record the depth at which the 300 psi level is exceeded, using the gradients on the penetrometer rod. This level is the top of the compacted zone. Continue pressing the penetrometer down. Record the depth at which the penetration falls below 300 psi. This is the bottom of the compacted zone. For each measuring point, there are two numbers: the top of the compaction zone and the bottom of the compaction zone. If penetration resistance never increases above 300 psi, you will have blanks in both spaces, indicating no severe root-limiting compaction. If the penetration resistance increases above 300 psi, but never falls below 300 psi, there is no bottom to the compaction zone.

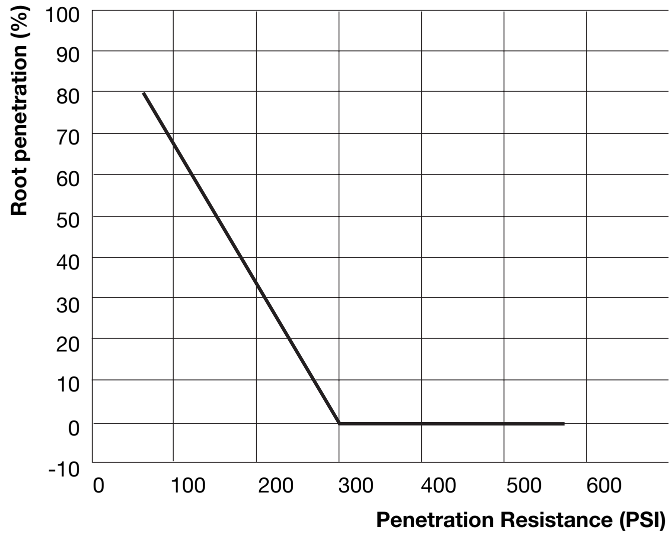
Cone index should be measured respective to tillage relief, wheel tracks, plant rows, and other recognizable patterns in the field. For example, if you know the areas of wheel traffic, take transects in and out of the track, and report them separately. If there are subsoiled zones in the field, measure penetration resistance in and out of the subsoiled zone. If there are planted rows, take measurements in and between the rows, and report them separately. Take separate readings for trafficked and non-trafficked areas.

The number of readings in a field depends on the accuracy you desire. As a first approximation, take some preliminary readings at a few places in the field to develop a sampling strategy. The cone index values are likely to be quite variable, so multiple readings are required per field. It is recommended to take one reading every 100 to 150 feet, or three to four readings per acre to develop a solid recommendation. This is a useful spacing if no recognizable patterns are present. If you recognize patterns, you may wish to increase the number of readings and report them separately as suggested above. It is extremely useful to compare the cone index values in the field with measurements in undisturbed areas such as fence rows.

After completing the sampling, a recommendation can be formulated using table 1.

The measurement of the lower boundary of the compaction zone determines the depth of subsoiling. If subsoiling is recommended, run the subsoiler 1 inch below the compaction zone. Setting the subsoiler much deeper will not provide additional benefits. If subsoiling is done, it is important to eliminate the cause of compaction to avoid recompaction. Subsoiling should only be considered to be a measure of last resort, not an annual management practice. These recommendations are based on research conducted at the University of Kentucky. With time, we hope to validate them in Pennsylvania.

Figure 2. Root penetration and penetration resistance.



The penetrometer simulates root growth. Root growth decreases linearly with increasing penetration resistance, until practically stopping above 300 psi. Remember, however, that roots may still penetrate soil with a penetration resistance greater than 300 psi if natural cracks and pores are present.

Table 1. Interpretation of penetration resistance measurements.

Percentage of measuring points having cone index > 300 psi in top 15 inches	Compaction rating	Subsoiling recommended
< 30	Little-none	No
30-50	Slight	No
50-75	Moderate	Yes
>75	Severe	Yes

Adapted from: Lloyd Murdock, Tim Gray, Freddie Higgins, and Ken Wells, 1995. Soil Compaction in Kentucky. Cooperative Extension Service, University of Kentucky, AGR-161.

Prepared by Sjoerd W. Duiker, assistant professor of soil management

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Agronomy Facts 71

Hairy Vetch as a Crop Cover

BENEFITS

Hairy vetch is an annual leguminous cover crop that is winter hardy throughout Pennsylvania if established in a timely manner. Hairy vetch fixes large amounts of nitrogen (N) that help meet N needs of the following crop, protects soil from erosion, helps improve soil tilth, and provides weed control during its vigorous growth in the spring and when left as a dead mulch at the soil surface. Hairy vetch can also be grazed or harvested as forage. Research has shown that hairy vetch mulch can increase main crop disease resistance and prolong leaf photosynthesis of the following crop.

ADAPTATION

Hairy vetch usually survives the winter in Pennsylvania as long as it is established in late summer/early fall. Hairy vetch does best on well-drained soils and is not recommended for poorly drained soils. It prefers a soil pH between 6.0 and 7.0 and is adapted to high soil fertility status (phosphorus, potassium, and sulfur). Some limited variety development has taken place in hairy vetch. ‘Madison’ was developed in Nebraska and is very cold tolerant. ‘Auburn’, ‘Oregon’, and ‘Lana’ are better adapted to warmer winters. Two new vetch varieties released by USDA are ‘Purple Bounty’ and ‘Purple Prosperity’. These varieties were developed for their earlier spring growth. However, there is some evidence that these varieties exhibit reduced winter hardiness. Despite the existence of hairy vetch varieties, most seed is labeled “variety not stated” (VNS). Additionally, varieties self-select to adapt to local conditions after being reproduced in a certain area for many years. Minnesota research has shown better winter survival of hairy vetch grown from locally produced seed than from seed produced farther south. Consequently, where the seed was produced is as important as the variety.

NITROGEN FIXATION

Hairy vetch can fix large amounts of nitrogen that are released rapidly after it has been terminated. Decomposition and nitrogen release rates are faster if the vetch is incorporated, but total amount of nitrogen released over the entire growing season is similar to vetch left on the surface as a mulch. The equivalent of 160 lbs/A N fertilizer can be released to the following crop by a killed hairy vetch cover, although 100 lbs/A N is more realistic. Typically, hairy vetch contains 3.5 to 4 percent nitrogen (dry matter basis). Conservative estimates are that 50 percent of this will be available to the following crop.

Figure 1. Hairy vetch as a crop cover.

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ESTABLISHMENT

Drill 15–20 lbs/A hairy vetch seed 1–1.5 inches deep (use higher seeding rate when planning to terminate hairy vetch early in spring). It is possible to broadcast seed at 20–30 lbs/A and use a light disking or field cultivation to improve seed to soil contact. Use seed that has been inoculated with the appropriate rhizobium strain (hairy vetch/pea group *Rhizobium leguminosarum biovar viceae)* to guarantee nitrogen fixation. For success, hairy vetch needs to be established in late summer (before mid-August in northern Pennsylvania and higher altitudes; September 1 in central Pennsylvania; and before the middle of September in southern Pennsylvania). Later establishment will usually lead to a poor stand due to winterkill. If established more than three weeks prior to latest establishment date, hairy vetch may winter-kill due to excessive fall growth.

A good place in a crop rotation for hairy vetch establishment is after small grain harvest. Make sure crop residue from the previous crop is well distributed if establishing hairy vetch with no-till methods and kill existing vegetation with a burndown herbicide. More often than not, a fair amount of volunteer small grain will come up with the hairy vetch in the fall. This should be considered an advantage rather than a disadvantage. The small grains provide a quick cover, whereas the hairy vetch grows slowly in the fall. The small grains help retain and absorb nutrients such as nitrogen, phosphorus, and potassium. The small grains also provide mulch that is more resistant to decomposition and contributes to the buildup of soil organic matter. The C/N (carbon-to-nitrogen) ratio of the residue tends to be lower if the small grain is grown in companion with hairy vetch, contributing to faster decomposition of the small grain residue and less nitrogen immobilization.

Each small grain/hairy vetch mixture has its advantages and drawbacks. In a mixed stand of hairy vetch and oats, the oats provide quick cover and capture snow that helps protect the young vetch seedlings in the winter. Since oats winterkill in most of Pennsylvania, there will be a pure hairy vetch stand left in the spring. If the companion is rye, triticale, wheat, or barley, the small grain will survive the winter with the hairy vetch. The small grain provides quick cover and the vetch climbs up into the small grains in the spring. Research in Maryland has shown that hairy vetch mixed with rye fixes almost the same amount of nitrogen as if it were grown without a companion. If volunteer small grain cannot be counted on, then it is recommended to seed a hairy vetch/small grain mix instead of pure hairy vetch. In this case, use no more than 2 bushels/A of oats or 1 bushel/A of rye, triticale, wheat, or barley mixed with a full seeding rate of hairy vetch. In spring, triticale and wheat mature at about the same time as hairy vetch, whereas rye will mature prior to hairy vetch flowering. Wheat and triticale may therefore be better suited in combination with hairy vetch if the goal is to terminate both at about the same stage of maturity prior to seed production.

It is possible to establish hairy vetch after early corn silage harvest in parts of Pennsylvania. However, attention needs to be paid to the herbicide program used; check the rotational restrictions on the label or in the *Penn State Agronomy Guide*. Although hairy vetch is not generally included as a rotational crop on the herbicide label, alfalfa and clover rotational restrictions should be similar to hairy vetch. Another option is to broadcast hairy vetch in standing soybeans, but this is uncommon because of the expense of the seed and the higher risk of failure with this method than if vetch is drilled. Seeding hairy vetch after corn grain or soybean harvest is not recommended because the vetch is then unlikely to survive the winter.

MANAGEMENT

Little management is usually required once hairy vetch is established. Fertilizer is usually not needed, and N fertilizer or manure applications can be detrimental because they stimulate grasses and small grains to be more competitive. Avoid traffic on hairy vetch as the wheels can destroy small seedlings as well as large plants.

TERMINATION

To fix much nitrogen, the hairy vetch should not be terminated too early in the spring (Table 1). This means that hairy vetch should be terminated after May 1 in southern Pennsylvania, after May 10 in central Pennsylvania, and after May 20 in northern Pennsylvania and higher altitudes. The vetch will still accumulate more nitrogen until early or mid-June, but the producer may wish to terminate the vetch before that to allow timely corn planting.

Table 1. Effect of termination date of hairy vetch in central Pennsylvania (established mid-August).

Vetch Termination Date	Vetch Dry Matter Biomass (lbs/A)	Vetch N Concentration (%)	Vetch N Content (lbs/A)	Estimated N Fertilizer Value (lbs/A)*
2007				
Early (May 4)	1,400	3.82	55	27
Middle (May 15)	4,300	4.43	190	95
Late (May 31)	6,600	4.15	274	137
2008				
Early (May 1)	3,200	2.49	80	40
Middle (May 14)	4,000	2.92	117	58
Late (May 31)	4,400	4.55	199	100

*Estimated based on 50 percent availability of vetch N. Data courtesy of Robert Gallagher.

A good herbicide program to terminate hairy vetch is a mix of glyphosate and 2,4-D or dicamba (Table 2). Glyphosate alone is not a recommended program to kill a legume such as hairy vetch since its performance is variable. Plant growth regulators such as 2,4-D and dicamba are effective but also require some delay (1–2 weeks) between application and corn planting to avoid corn herbicide injury. For faster dessication, use paraquat and 2,4-D or paraquat and atrazine. Several other herbicides may also help manage hairy vetch in corn without having to delay corn planting. Using a herbicide for termination of hairy vetch and no-till establishment of the following crop helps maintain more benefits such as superior soil protection and greater moisture conservation than if tillage is used. The hairy vetch should be allowed to dry down for about 10–14 days to facilitate ease of planting. The threat of hair pinning of residue in the seed slot is greatest when no-till planting into a vetch cover that is dying but not dry and crisp. Monitor seeding depth of corn and that hairy vetch vines do not wrap around row cleaners. If the latter occurs, lift row cleaners up.

If tillage is used, it is important to realize that most conservation tillage tools such as chisel plows or disks are unlikely to completely kill the hairy vetch. The vines of hairy vetch, which can be 4 feet tall, tend to wrap around chisel shanks, making this tool unsuitable to incorporate hairy vetch cover crops. If using a chisel plow, it is recommended to shred the vetch using a tool such as a flail mower before plowing. Vetch does not tend to wrap around disk plow assemblies, but incorporation of the vetch may not be sufficient to allow seedbed preparation. The moldboard plow is the most effective tillage tool for fully incorporating and killing a heavy hairy vetch stand. It is important to have a lead coulter in front of each plow bottom to avoid wrapping of hairy vetch vines on the standard assembly. Unfortunately, the moldboard plow has been shown to have greater negative effect on soil than any other common tillage tool used in field crop production.

Organic growers are interested in using hairy vetch and no-till corn, but they cannot use herbicides. Investigations have started into killing hairy vetch with a hollow drum with blunt blades and then no-tilling corn into the mulch. The timing of this practice is essential for success. Penn State research has shown that hairy vetch is consistently killed when rolled after the first pods appear on the vetch plants, which is not until late May in southern Pennsylvania and early to mid-June in central Pennsylvania. Rolling and immediately planting has provided the greatest vetch control and weed suppression. The thick vetch mulch provides a good weed-suppressing mat, making further weed control usually unnecessary. It is important to minimize mulch and soil disturbance when planting the main crop to avoid stirring up weed seeds. If the hairy vetch mulch does not adequately control weeds in this system, additional control measures using a high-residue cultivator or other postemergence strategies will be necessary.

Hairy vetch contains from 0 to 25 percent hard seed (seed that does not immediately germinate). This seed can come up in future years as a weed in winter small grains. Research is ongoing to develop methods to reduce hard seed by scarification or other methods. At present it is recommended to use hairy vetch no more than once every three years in the rotation to avoid problems with volunteer vetch in small grains.

Table 2. Effectiveness of herbicides for control of selected legume cover crops.

	Rate (lbs ae or ai/acre)	Hairy Vetch	Crimson Clover	Austrian Winter Pea
Glyphosate[1]	0.37	6	6	6
	0.75	7	7	7
	1.50	8	8	8
Paraquat	0.50	7	7	7
	0.75	8	7	8
2,4-D LVE	0.25	8+	7	8
	0.50	9+	8	9
Dicamba	0.25	8+	8+	8+
	0.50	9+	9+	9+
2,4-D + dicamba	0.50 + 0.25	10	10	10
	0.50 + 0.50	10	10	10
Clopyralid	0.195	9	9	9
Atrazine	1.00	7	7	7
	2.00	8	8	8
Paraquat + 2,4-D LVE	0.75 + 0.25	9+	9	9
Glyphosate + 2,4-D LVE	0.75 + 0.25	9	9	9
Paraquat + atrazine	0.75 + 1.0	9	9	9
Glyphosate + atrazine	0.75 + 1.0	8	8	8

Ratings are based on labeled application rates (0 = no control, 10 = complete control). Results may differ with variations in cover crop size, temperature, and rainfall. Only glyphosate, paraquat, or 2,4-D may be used prior to seeding soybean. Follow label guidelines. Herbicides should be applied to cover crops with at least 6 inches of spring growth.

1. Glyphosate rate in lbs ae/acre; 0.5 lb paraquat = 2 pt Gramoxone Inteon; 0.195 lbs clopyralid = 5 oz Hornet 78.5WDG or 6.7 fl oz Stinger 3S.

MANAGEMENT SUMMARY

Seeding rate: 15–30 lbs/A (lower rate if drilled; higher when tilled in)

Seeding depth: 1–1.5 inch

Inoculation: use vetch/pea *Rhizobium* inoculant

Biomass accumulation: mostly in the spring (April/May)

Nitrogen fixation: mostly in the spring (April/May)

Burndown herbicide: 2,4-D, dicamba, clopyralid, or mixes

Soil preparation and main crop planting: vetch vines can wrap around tillage shanks or row cleaners

Prepared by Sjoerd W. Duiker, associate professor of soil management; William S. Curran, professor of weed science; and Robert S. Gallagher, associate professor of cropping systems.

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Cooperative Extension
Northampton County

14 Gracedale Avenue
Greystone Building
Nazareth PA 18064-9212

(610) 746-1970
Fax: (610) 746-1973
E-mail: NorthamptonExt@psu.edu
Website: northampton.extension.psu.edu

Calculating nitrogen availability from your legume cover crop

Example: Cynthia grew a cover crop of clover over the winter, but the clover did not grow very well. She only got about 50% groundcover and the clover grew 8" tall. She thinks the amount of nitrogen she grew was not enough and will have to apply additional N to meet her crop nitrogen needs. First she wants to determine how much nitrogen her cover crop provided.

Lbs of cover crop:

Inches > 6: ___8___ inch – 6 inches =___2___inches cover crop > 6 inches tall.

___2___inches x 150 lbs dry matter/ inch cover crop = ___300___ lbs/acre.

Add 2,000 lb/acre for first 6 inches:

2,000 lbs/acre + ___300___ lbs/acre = ___2,300___ lbs/acre cover crop dry matter at 100% cover

Multiply by percent cover:

2,300 lbs/acre x ___50%___ = ___1,150___ lbs/ acre dry matter

Multiply by the cover crop percent nitrogen:

___1,150___ lbs/acre x 3.5% nitrogen = ___40.25___ lbs/acre

Assume 50 % of cover crop nitrogen available in year 1: ___40.25___ lbs N /acre_x 50% = ___20.13___ lbs nitrogen /acre

Calculate your cover crop nitrogen contribution:

Lbs of cover crop:

Inches > 6: _________ inch – 6 inches =_________inches cover crop > 6 inches tall.

__________inches x 150 lbs dry matter/ inch cover crop = __________ lbs dry matter/acre

Add 2,000 lb for top 6 inches:

2,000 lbs/acre + __________ lbs/acre = __________ lbs/acre cover crop dry matter at 100% cover

Multiply by percent cover:

_________ x __________(%) = __________ lbs/ acre dry matter

Multiply by the cover crop percent nitrogen:

__________ lbs/acre x .035 (3.5%) nitrogen = __________ lbs/acre

Multiply by % of cover crop nitrogen available in year 1: __________ lbs N /acre x .5 (50%) (general estimation) = _________ lbs nitrogen available/acre

[1] This information is adapted from1. Clark, A., ed. *Managing Cover Crops Profitably*. Sustainable Agriculture Network Handbook Series. 2007, Sustainable Agriculture Network: Beltsville, MD.

Summary of the Cover Crops Frequently Grown in the Northeast US

Species	Seeding Rate	Cost ($ per unit)	Seeding Date	Winter-hardy?	Advantages for this species	Disadvantages for this species
Rye	1 - 1.5 bu (mix) 2 - 3 bu (alone)	6 - 10 (farm grown) 12 – 16 (cert. Seed)	Early Aug-Early Nov	Very	• can successfully be planted the latest of all species • grows the longest into the fall • earliest to begin spring growth • profuse, dense, deep root system able to hold soil and build structure • able to take up and hold nutrients (esp. N) • able to produce large amounts of biomass, compete with weeds • allelopathic effect on weeds	• can "get away" from farmer, producing more biomass than able to plant through • able to use a lot of water, resulting in dry seedbed for following crop
Triticale	1 - 1.5 bu (mix) 2 - 3 bu (alone)	12 - 20 (cert. seed)	Early Aug-Oct	Most are very	• similar to rye, but not as aggressive • usually not able to produce as much biomass as rye	• low supply of farm-produced seed • reduced capacity for soil improvement compared to rye
Wheat	1 - 1.5 bu (mix) 2 - 3 bu (alone)	5 – 7 (farm) 8 – 16 (cert. seed)	Sept - Oct	Most are very	• similar to rye, less aggressive than rye or triticale	• concern for Hessian Fly infestation when planted before fly-free date • reduced capacity for soil improvement compared to rye
Oats	1.5 - 2 bu (mix) 3 - 4 bu (alone)	3 – 6 (farm) 8 – 12 (cert. seed)	July-late Sept	No	• produces a lot of fall growth very quickly • able to take up excess nutrients in fall • works well as nurse crop for other species that are winterhardy and able to grow well in spring • easy spring management; good ahead of no-till alfalfa	• leaves field with a dead residue, not taking up nutrients after winterkilled • residue may breakdown quickly, leaving field open to possible erosion in late spring • needs to be planted early

Species	Seeding Rate	Cost ($ per unit)	Seeding Date	Winter-hardy?	Advantages for this species	Disadvantages for this species
Annual ryegrass	5 - 10 lbs (mix) 10 - 15 lbs. (alone)	0.50 - 0.60	Aug - Sept	Variety and planting date dependent	• vigorous root system • relatively low seed costs • high quality forage if needed	• too much fall growth (>6 in.) can result in winterkill • can be challenge to control with herbicides • potential weed if allowed to produce viable seed • needs to be planted early
Tillage Radish	3 – 8 lbs (mix) 8 – 12 lbs (alone)	3.00 – 4.00	July – Aug	No	• quick establishment • able to alleviate soil compaction • provides weed suppression • fall nitrogen scavenger • faster soil warm-up in spring	• minimal soil protection in spring • no N uptake in spring • needs to be planted early
Austrian Winter Pea	40 – 80 lbs	0.90 – 1.10	Aug – Sept	Yes	• legume: nitrogen fixation capabilities	• not a good soil cover, esp. in fall • seed cost is high • needs to be planted early
Hairy Vetch	15 – 20 lbs	2.40 – 2.70	Aug – Sept	Depends on seed source	• legume: highest potential for nitrogen fixation of commonly grown legumes for NE • nitrogen availability is synchronized with corn N needs	• not a good soil cover, esp. in fall • slow fall growth, until early April • hard seed can create a weed problem • seed cost is high • needs to be planted early
Crimson Clover	10 – 15 lbs	1.00	Aug – mid Sept	Depends on establish-ment date	• legume: nitrogen fixation capabilities • faster establishment, fall cover, and spring growth than other legumes • modest seed costs; lower cost of establishment	• hairpinning potential when no-till planting into mature crimson clover
Red Clover	8 – 12 lbs	1.50 – 2.50	July – mid Sept	Yes	• regarded as the most winterhardy legume used in the region • able to provide forage if needed	• reduced nitrogen fixation if fall planted • needs to be planted early

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Using Organic Nutrient Sources

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Introduction

When using organic nutrient sources—for example, compost, manure, green manures, meals, and so forth—recommendations for crop nutrient needs will need to be translated. Soil test reports do not give specific recommendations for using organic fertilizers/amendments. This is because the percentage and availability of plant nutrients in such materials is highly variable and usually depends on its source, method of storage, and the amount and type of materials used to make the nutrient source. Generally, the low nutrient content and often limited sources of many organic materials add to the difficulty in developing a specific recommendation.

This guide is intended to help growers interpret soil test recommendations for using organic nutrient sources. Information presented applies to organic and conventional farms.

USDA National Organic Standards Summary on Soil Fertility Management

For all growers, the goals of soil fertility management are to provide sufficient nutrients to the crop grown, maintain or improve the soil condition, and minimize erosion. Organic growers are required to implement strategies to achieve these goals as indicated by USDA's national organic standards. Practices include using sound crop rotations, green manures, and cover crops and applying plant and animal matter and allowable soil amendments according to the national list.

National Organic Standards Summary for Fertilizers and Soil Amendments Use

Fertilizers and soil amendments that are in compliance with the national organic standards are available to complement other fertility practices. In addition, mined substances of low solubility can be used to supply plant nutrients. Plant or animal ashes can also be used to improve soil fertility as long as they have not been combined or treated with a prohibited substance and are not themselves a prohibited substance.

Soil Testing

Good crop yields can be expected over a rather wide range of nutrient levels in most soils. The most desirable level of each nutrient depends on such variables as the amount of rainfall, temperatures, amount of sunlight, soil texture, soil drainage, prevalence and severity of plant diseases, and the crop cultivar grown.

The more intensive the type of production, the more important the information provided by a soil test. The Agricultural Analytical Services Laboratory at Penn State analyzes soil samples for pH, calcium, magnesium, potassium, and phosphorous levels. If requested, the lab will also determine the organic matter content and salt levels of soil samples for an extra fee. Soil samples must be submitted in standard sampling and mailing kits, which can be purchased from local Penn State Cooperative Extension offices.

Other laboratories also conduct soil analysis. Whatever soil testing system is used, it is important to stick with it and develop a feel for the relationship between test results and the response of the growing crops. Crop response with balanced fertility is what really counts.

Soil Test Values

Soil test values reported from the Agricultural Analytical Services Laboratory are interpreted as "deficient," "optimum," or "exceeds crop needs" (see Figure 1.). Crops normally produce best when nutrients are present in balanced amounts at "optimum" levels. Application of a nutrient shown to be "deficient" should increase yield. When levels fall in the "exceeds crop needs" category, more than enough of a nutrient is present.

When Nutrient Levels Exceed Crop Needs

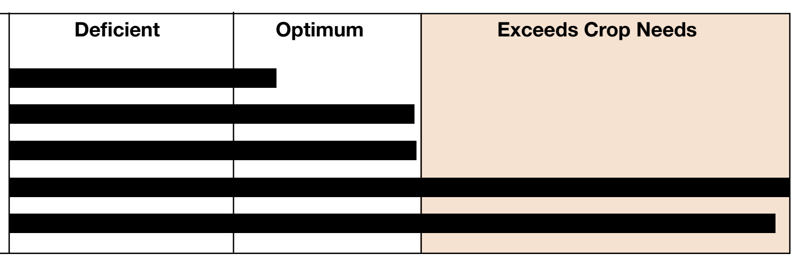
Soil nutrient levels that exceed crop needs can be as bad as deficient levels. High soil nutrient levels might not only represent an economic loss but may also result in crop, animal, or environmental problems. To achieve maximum yield and quality from each crop, a specific balance among elements is necessary. Very high phosphorus levels (above about 310 pounds P_2O_5 per acre or 140 pounds of phosphorus per acre for vegetable crops) in the soil may lead to deficiencies of other nutrients, especially of iron and zinc. If potassium, magnesium, or calcium

Figure 1. ***Example soil test report illustrating "deficient," "optimum," and "exceeds crop needs" categories for nutrient levels.***

SOIL TEST REPORT FOR:	ADDITIONAL COPY TO:

DATE	LAB #	SERIAL #	COUNTY	ACRES	FIELD ID	SOIL
11/12/2004	S00-02986		0		2122	

SOIL NUTRIENT LEVELS			
Soil pH		6.5	
Phosphate	(P_20_5)	321.0	lb/A
Potash	(K_20)	336.0	lb/A
Magnesium	(Mg0)	1813.0	lb/A
Calcium	(Ca0)	6088.0	lb/A



Recommendations for:	*SWEET CORN (FRESH MARKET)*

is high, serious nutrient imbalances can occur. When potassium levels are above about 5 percent saturation, magnesium levels 15 percent, and calcium levels 80 percent, soil nutrition is beginning to get out of the optimum range. Use best management practices to avoid increasing nutrient levels that already exceed crop needs. Yield and quality are likely to be reduced by reapplying a nutrient already present in very high amounts.

Balance and Imbalance of Nutrients in Organic Nutrient Sources

An unbalanced plant-nutrient status can be the result of using either organic or inorganic fertilizers. Most organic materials (including compost) do not contain nutrients in balanced amounts as needed by plants. In particular, many nutrients from animal sources (e.g., manure) have an excess of phosphorus and potassium relative to plant demand for nitrogen. In soil these nutrients can accumulate to levels exceeding crop needs with repeated application based on plant nitrogen needs. When using organic materials, regularly soil test to monitor phosphorus, potassium, and salt accumulation. Nutrient amendments should also be tested regularly, as similar organic materials may vary considerably in nutrient content depending on their source, handling, and conditions present when the plant or organism was living. The use of other sources of plant nutrients may be necessary to correct imbalances (for example, legume green manure crops that contribute nitrogen without increasing phosphorus and potassium).

Nutrient Availability from Organic Nutrient Sources

Suggested amounts of organic amendments or fertilizers to be applied in lieu of chemical or inorganic fertilizers may or may not be equally effective because of differences in the physical and chemical nature of organic materials. Most nutrients from organic materials are very slowly to slowly available to plants compared to inorganic fertilizers. Tables 2 and 3 give a general rating on the availability of many organic materials. Materials rated "very slow" to "medium" in nutrient availability may be used to maintain a given level and nutrient balance in the soil. Where a rapid change in nutrient levels or balance is necessary, materials having "medium" to "rapid" nutrient availability should be used.

Increasing Soil pH, Calcium, and Magnesium Levels

If soil test results indicate a need for a liming material to increase soil pH, calcium, or magnesium levels, the use of these materials is the first step in soil management. Whenever possible, a liming material should be applied during fall prior to planting to provide several months for these materials to begin reacting with soil particles. Table 1 lists materials used to increase soil pH. The liming potential of wood ashes (32 percent calcium oxide, CaO) is such that 3 pounds of wood ashes is equal to 2 pounds of ground limestone (50 percent CaO). If soil pH is 6.8 or above, wood ashes should not be used.

Decreasing Soil pH

If soil test reports indicate that the soil pH exceeds optimum, it will need to be lowered. Some materials for lowering soil pH include sulfur, peat moss, and cottonseed meal. For large areas sulfur is likely the most economical option. Elemental sulfur and iron sulfate can be used in organic production. Both of these products are labeled as "restricted" according to the Organic Materials Review Institute (OMRI), which means that they are allowed in organic production but are subject to meeting certain criteria (check with your certifying agency before using). Sulfur reacts slowly with soil particles; therefore, allow several months for changes in soil pH to occur. Whenever possible, apply sulfur well in advance of planting to provide sufficient time for reacting with soil particles.

Table 1. Materials used to increase soil pH.

Material	Calcium oxide (CaO)	Status for organic production[a]
Clam shells (finely ground)	50%	allowed
Ground shell marl (at least 75% passes a 100-mesh sieve)	35–42%	allowed
Oyster shells	43–50%	allowed
Wood ashes	32%	allowed
Limestone		
Dolomite (mined)	More than 15% MgO + 35% CaO	allowed
Calcitic	45%–50% CaO equivalent	allowed

a. Must be produced in accordance with the national organic standards to be allowable on certified organic farms. Organic status was determined through listing with the Organic Materials Review Institute (OMRI; www.omri.org) or Pennsylvania Certified Organic (www.paorganic.org). The brand of the material used may affect allowability; check with your certifier before using any product to avoid compromising your certification.

Peat moss has a pH between 3.0 and 5.0, depending on type. It is allowable in organic crop production; however, the type used cannot contain a synthetic wetting agent. Cottonseed meal is a fertilizer (see Table 3) that also has a low pH and can be used to decrease the soil pH. It is approved for organic production as long as it is not from genetically modified cotton and is free from prohibited substances. Peat moss and cottonseed meal can be expensive and are more suited for applications on small areas. For example, blueberry growers have applied peat moss in planting holes. With all these materials, it is best for organic growers to work closely with their certifying agency before applying them to ensure that organic certification is not compromised by their use.

Recommendations for Nitrogen, Phosphate, and Potash

Fertilizer recommendations for crop production are expressed in amounts of N (nitrogen), P_2O_5 (phosphate), and K_2O (potash) per acre. Recommendations from the Agricultural Analytical Services Laboratory at Penn State are given for inorganic fertilizers and expressed in units of pounds per acre (lb/A).

Adding Phosphate

A soil with a deficient phosphorus level may present a problem when relying exclusively on organic materials. Rock phosphate is the most economical organic source of phosphorus allowed in organic farming. Raw rock phosphate, even when it is from high-grade minerals and finely ground, has been quite ineffective on soils with a pH much higher than 6.0, due to low solubility and exceedingly slow reaction time. Rock phosphate needs acids to bring about the release of P_2O_5 (phosphate) for plant use; hence, it is most efficiently used on acid soils. In acid soils P_2O_5 may be available to plants in subsequent seasons following application. Although rock phosphate contains 20 to 32 percent P_2O_5, available P_2O_5 is only 5 percent.

When phosphorus is deficient it can be more efficient to add raw rock phosphate to manures or when making compost piles, rather than as a soil application. Microbial activity and localized acidity in manures and composts can increase the availability of the phosphate. However, adding phosphorus will exacerbate the previously mentioned imbalance in manures and composts. Phosphorus and nitrogen must also be considered. If manures or composts are relied on as an N amendment, over time the excess of phosphorus over N relative to plant demand will result in accumulations of phosphorus at N amendment rates. Other sources of P_2O_5 are listed in Tables 2 and 3. Before using any listed materials, it is best for organic growers to check with their certifying agency.

In planning for long-term production, apply raw rock phosphate or any other slowly available plant nutrient well in advance (at least six months to one year) of actual planting. If a high initial application of raw rock phosphate is applied, decreasing amounts will be needed in subsequent years. The increase in available phosphorus will be reflected in future soil test results.

Adding Nitrogen and/or Potash

A number of organic materials may be used to supply N and K_2O (Tables 2 and 3). Before using any listed materials, it is best for organic growers to check with a certifying agency to ensure that organic certification is not compromised by their use. Nutrient contents of the materials and the relative nutrient availabilities are listed.

Table 2. Mineral nutrient value of natural deposits useable as fertilizers.

Material	Status for organic production[a]	Nutrients (percent)[b]			Relative availability
		N	P_2O_5	K_2O	
Colloidal phosphate	Allowable[c]	0	25.0	0	Slow
Granite meal	Allowable	0	0	3.0–5.0	Very slow
Greensand	Allowable	0	1.35	4.0–9.5	Very slow
Kainite	Restricted[d]	0	0	12.0	Medium
Rock phosphate	Allowable	0	20.0–32.0	0	Very slow
Sodium nitrate	Restricted[e]	16.0	0	0	Rapid

a. Based on the Organic Materials Review Institute (OMRI) Generic Materials List (June 2004).

b. The percentage of nutrients is highly variable and differs with place of origin. Availability of nutrients from natural deposits depends largely on the fineness to which these materials are pulverized.

c. Brand used may affect allowability; check with your certifying agency before using any product to avoid compromising your certification.

d. Can be used provided it is "derived from a mined source and applied in a manner that minimizes chloride accumulation in the soil" (NOS 205.203[d][3] and 205.602[e]).

e. Cannot account for more than 20 percent of the nitrogen requirements of the crop grown. Its use is prohibited by the International Federation of Organic Agriculture Movements (IFOAM) and most other standards for organic production outside the United States.

Table 3. Mineral nutrient value, relative availability and status for organic production of various nutrient sources. Before using any of the listed materials, it is best for organic growers to check with their certifying agency to ensure that organic certification is not compromised by their use.

Materials[a]	Status for organic production[b]	Nutrients (percent)[c]			Relative availability
		N	P_2O_5	K_2O	
Animal tankage (dry)	Allowable	7.0	10.0	0.5	Medium
Bone meal (raw)	Allowable	2.0–6.0	15.0–27.0	0	Slow
Bone meal (steamed)	Allowable	0.7–4.0	18.0–34.0	0	Slow medium
Cocoa shell meal	Allowable	2.5	1.0	2.5	Slow
Compost (not fortified)	Allowable[d]	1.5–3.5	0.5–1.0	1.0–2.0	Slow
Cottonseed meal (dry)	Allowable[e]	6.0	2.5	1.7	Slow medium
Dried blood (dry)	Allowable	12.0	1.5	0.57	Medium rapid
Fertrell—Blue Label 1-1-1	Not OMRI listed; determined restricted by PCO[f]	1.0	1.0	1.0	Slow
Fertrell—Gold 2-1-2	Not OMRI listed, determined restricted by PCO[f]	2.0	1.0	2.0	Slow
Fertrell—Super 3-2-3	Not OMRI listed; determined allowed by PCO	3.0	2.0	3.0	Slow
Fertrell—Feed-N-Gro 4-2-4	OMRI approved	4.0	2.0	4.0	Slow
Fertrell—Feed-N-Gro 2-2-4	OMRI approved	2.0	2.0	4.0	Medium
Fertrell—Feed-N-Gro 3-2-3	OMRI approved	3.0	2.0	3.0	Medium rapid
Fertrell—Feed-N-Gro 2-4-2	OMRI approved	2.0	4.0	2.0	Medium
Fertrell—Feed-N-Gro 4-2-4	OMRI approved	4.0	2.0	4.0	Medium rapid
Fertrell—Berry Mix	Not OMRI listed; determined restricted by PCO[f,g]	4.0	2.0	4.0	Medium rapid
Fertrell—2-4-4	Not OMRI listed; determined restricted by PCO[g]	2.0	2.0	4.0	Medium
Fertrell—5-3-3	Not OMRI listed; determined restricted by PCO[g]	5.0	3.0	3.0	Rapid
Fertrell—Rock Phosphate	OMRI approved	0	3.0	0	Very slow
Fertrell—SQM Nitrate of Soda 16-0-0	OMRI restricted[h]	16.0	0	0	Rapid
Fertrell—Feed-N-Gro Omega Grow	OMRI approved	5.0	1.0	1.0	Rapid
Fertrell—Liquid #14-1-1	OMRI approved	5.0	1.0	1.0	Rapid
Fertrell—Jersey Greensand	OMRI approved	0	0	3.0	Very slow
Fertrell—Kelp Meal	OMRI approved	1.1	0.9	4.0	Slow
McGeary Organics—5-3-4	OMRI approved	5.0	3.0	4.0	Contains blood meal: rapid; soybean meal: medium; compost: slow
McGeary Organics—3-5-3	OMRI approved	3.0	5.0	3.0	Contains blood meal: rapid; soybean meal: medium; compost: slow
McGeary Organics—2-3-4	OMRI approved	2.0	3.0	4.0	Medium
McGeary Organics—8-1-1	OMRI approved	8.0	1.0	1.0	Very rapid
McGeary—Organics 6-0-4	OMRI approved	6.0	0	4.0	Contains blood meal: rapid; soybean meal: medium; compost: slow
McGeary Organics—0-2-9	OMRI approved	0	2.0	9.0	Very slow
Fish emulsion	Allowable	5.0	2.0	2.0	Rapid
Fish meal (dry)	Allowable	14.0	4.0	0	Slow
Fish scrap (dry)	Allowable	3.5–12.0	1.0–12.0	0.08–1.6	Slow
Garbage tankage (dry)	Allowable	2.7	3	1	Very slow
Grain straw	Allowable	0.6	0.2	1.1	Very slow
Guano (bat)	Restricted[i]	5.7	8.6	2.0	Medium
Kelp[j]	Allowable	0.9	0.5	4.0–13.0	Slow
Manure[k] (fresh)	Restricted[l]				
Cattle		0.25	0.15	0.25	Medium

Materials[a]	Status for organic production[b]	Nutrients (percent)[c]			Relative availability
Horse		0.3	0.15	0.5	Medium
Sheep		0.6	0.33	0.75	Medium
Swine		0.3	0.3	0.3	Medium
Poultry (75%)		1.5	1.0	0.5	Medium rapid
Poultry (50%)		2.0	2.0	1.0	Medium rapid
Poultry (30%)		3.0	2.5	1.5	Medium rapid
Poultry (15%)		6.0	4.0	3.0	Medium rapid
Marl	Allowable	0	2.0	4.5	Very slow
Milorganite (dry)	Prohibited	5.0	2.0–5.0	2.0	Medium
Mushroom compost[m]	Restricted[n]	0.4–0.7	5.7–6.2	0.5–1.5	Slow
Peanut hulls	Allowable	1.5	0.12	0.78	Slow
Peat and muck	Allowable[o]	1.5–3.0	0.25–0.5	0.5–1.0	Very slow
Pomaces[p]	Allowable				
Apple (fresh)		0.17–0.3	0.4–0.7	0.2–0.6	Slow
Apple (dry)		0.7–0.9	1.2–2.1	0.6–1.8	Slow
Castor		5.0	1.0	1.0	Slow
Winery		1.5	1.5	0.80	Slow
Sawdust	Allowable[q]	4.0	2.0	4.0	Very slow
Sewage sludge (activated, dry)	Prohibited	2.0–6.0	3.0–7.0	0–1.0	Medium
Sewage sludge (digested)	Prohibited	1.0–3.0	0.5–4.0	0–0.5	Slow
Soybean meal (dry)	Allowable	6.7	1.6	2.3	Slow medium
Tobacco stems (dry)	Allowable	2.0	0.7	6.0	Slow
Urea	Prohibited	42.0–46.0	0	0	Rapid
Wood ashes[r]	Restricted[s]	0	1.0–2.0	3.0–7.0	Rapid

a. Some materials may not be obtainable because of restricted sources.

b. Must be produced in accordance with the national organic standards to be allowable. Organic status was determined through listing with the Organic Materials Review Institute (OMRI; www.omri.org) or Pennsylvania Certified Organic (www.paroganic.org; list expires June 30, 2009). Brand used may affect allowability; organic growers should check with their certifier before using any product to avoid compromising certification.

c. The percentage of plant nutrients is highly variable; mean percentages are listed.

d. Must be produced in accordance with the national organic standards to be used in organic production.

e. Brand used must not be derived from genetically modified cotton or contain prohibited substances before soil incorporated. (OMRI, Generic List June 2004)

f. Can be applied to the soil without restriction, but must be tested for pathogens when used in foliar applications or not soil incorporated. Approval list expired June 30, 2009.

g. Must have a documented micronutrient deficiency to use. Approval list expired June 30, 2009.

h. Cannot account for more than 20 percent of the nitrogen requirements of the crop grown. Its use is prohibited by the International Federation of Organic Agriculture Movements (IFOAM) and most other standards for organic production outside the United States.

i. Must be decomposed and dried deposits from wild bats or birds. Domesticated fowl excrement is considered manure, not guano. (OMRI, Generic List June 2004)

j. Contains common salt, sodium carbonates, sodium, and potassium sulfates.

k. Plant nutrients are available during year of application. Nutrient content varies with the amount of straw and method of storage.

l. Uncomposted animal manure must be used on fields with crops not to be consumed by humans or incorporated into the soil a minimum of 90 days before harvesting a product to be consumed by humans, provided that the edible portion of the crop does not contact the soil or be incorporated into the soil a minimum of 120 days before harvesting a product to be consumed by humans that does come into contact with the soil. Using sewage sludge is prohibited in certified organic production.

m. Fresh mushroom compost is usually high in soluble salts.

n. Must be from certified organically grown mushroom production systems or be produced in a manner that prevents contamination with prohibited substances. Must meet compost requirements. (OMRI, Generic List June 2004)

o. Must not contain synthetic wetting agents. Observe worker safety precautions; use a dust mask when handling to prevent lung irritation or infection. (OMRI, Generic List June 2004)

p. Plant nutrients are highly variable, depending on the efficiency and the processing techniques at the processing plant.

q. From untreated and unpainted wood only. (OMRI, Generic List June 2004)

r. Potash content depends upon tree species burned. Wood ashes are alkaline and contain about 32 percent CaO.

s. Ash from plant and animal sources only. Use wood stove ash only if not contaminated with colored paper, plastics, or other synthetic sources. (OMRI, Generic List June 2004)

Calculating Sodium Nitrate (Chilean Nitrate) that Can Be Applied on Organic Farms

Sodium nitrate, also known as chilean nitrate, cannot account for more than 20 percent of the N requirements of organic crops in the United States. Its use is also prohibited by the International Federation of Organic Agriculture Movements (IFOAM) and most other standards for organic production outside the United States. To calculate the amount of sodium nitrate permitted, first determine the amount of nitrogen recommended for the crop. This information varies by crop and can be found on soil test reports or in production guides such as the *Commercial Vegetable Production Recommendations* guide for Pennsylvania. Next, multiply the recommended rate by 0.20 (20 percent) to determine how much of the recommended nitrogen can be satisfied by sodium nitrate.

___ lbs N recommended/acre x 0.20 = ___ lbs N/acre that can be supplied by sodium nitrate

Example:

80 lbs N recommended/acre (crop dependent; from soil test report or the *Commercial Vegetable Production Recommendations* guide for Pennsylvania) x 0.20 = 16 lbs N/acre that can be supplied by sodium nitrate

Sodium nitrate has an analysis of 16-0-0. This means that nitrogen composes 16 percent of it or, in other words, that 16 pounds of nitrogen are in 100 pounds of sodium nitrate. To determine how much sodium nitrate to apply, multiply the amount of nitrogen per acre that can be supplied by sodium nitrate by 6.25 (100 lbs sodium nitrate ÷ 16 lbs nitrogen = 6.25).

___ lbs N/acre that can be supplied by sodium nitrate x 6.25 = ___ lbs of sodium nitrate/acre to apply

Example:

16 lbs N/acre that can be supplied by sodium nitrate x 6.25 = 100 lbs of sodium nitrate/acre to apply

Therefore, if the recommendation is to apply 80 pounds of nitrogen per acre, you can apply 100 pounds of sodium nitrate per acre, which will supply 16 pounds of nitrogen per acre. The balance of the crop's nitrogen needs will need to be supplied through other nitrogen sources approved for use in organic production.

Adding Nitrogen with Leguminous Green Manures

Green manures are crops that are turned into the soil while they are young and succulent, rather than harvested. They can be grown for different purposes: adding nitrogen to the soil, suppressing weeds, scavenging nutrients left in the soil, or increasing the soil organic matter content.

Legume crops can add nitrogen to the soil. They are able to establish relationships with soilborne bacteria that are capable of extracting nitrogen gas from the atmosphere and converting it into a form that the plant can use. Seed of legumes may need to be inoculated with these bacteria; inoculants are commercially available. Inoculants are specific to the legume species grown, so chose a compatible inoculant. Also, not all brands of inoculants are allowable in organic production. Organic growers should check with their certifying agency before using.

As a result of the relationship between soilborne bacteria and legume roots, the tissues of leguminous crops have a lot of nitrogen relative to the amount of carbon,

Table 4. Approximate nitrogen credit from the use of nitrogen-fixing legumes.

Nitrogen-fixing legume	N (lbs/acre)[a]
Alfalfa sod	50–100[b]
Clovers	
Alsike	60–119[c]
Berseem	50–95[c]
Crimson clover sod	50
Ladino clover sod	60
Red	100–110[c]
White	≤130
Cowpeas	130
Fava beans	71–220[c]
Field peas	172–190[c]
Hairy vetch	50–100[b]
Sweetclovers	
Annual white	70–90[c]
Biennial	90–170[c]
Birdsfoot trefoil	40
Lespedeza	20
Soybeans	
Tops and roots	40
Grain harvest residue	15

Adapted from the *Commercial Vegetables Recommendations* guide for Pennsylvania (Penn State Cooperative Extension publication AGRS-028) and the *Northeast Cover Crop Handbook* (by Marrianne Sarrantonio, Rodale Institute)

a. Nitrogen contributed to the soil varies depending on plant biomass (volume of aboveground growth) produced. Biomass production is related to percent stand, the length of the growing season for the nitrogen-fixing legume, and management practices; table values are approximate.

b. 75 percent stand = 100-0-0; 50 percent stand = 75-0-0; and 25 percent stand = 50-0-0.

c. Use values on the lower end of the range when biomass is small and values on the higher end of the range when biomass is large.

which results in their decomposing rather quickly when turned into the soil. This results in a relatively quick release of nitrogen as the plants decompose, but the amount of organic matter added to the soil is limited over the long term. Leguminous crops differ in the amount of nitrogen they can add to the soil as shown in Table 4.

Other methods for estimating nitrogen added to the soil from a green manure crop that are more discerning for biomass production are available. Two sources for such methods are the *Northeast Cover Crop Handbook* by Marianne Sarrantonio (1994, Rodale Institute) and *Managing Cover Crops Profitably*, 3rd edition, edited by Andy Clark (2007, the Sustainable Agriculture Network).

Soil Organic Matter Content

Most crops grow best in soils with organic matter contents between 2 and 5 percent. Organic matter serves beneficial functions, including minimizing soil temperature fluctuations, serving as a nutrient warehouse, buffering the soil to changing pH, and increasing the ability of the soil to hold nutrients. Additionally, soil structure can be improved along with the ability of the soil to hold water and air. Organic matter can also provide habitat for beneficial soil microorganisms. A soil with an optimal organic matter content is better able to tolerate adverse conditions. For example, during drought conditions or when excess water is present, a soil with a good organic matter content will rebound quicker than one with a low organic matter content. The organic matter content of a soil can be analyzed as an additional test when submitting a soil sample to the Agricultural Analytical Services Laboratory at Penn State.

Mineralization

Nitrogen for plant use is released from organic matter as it is broken down by soil microorganisms, a process formally called mineralization. The rate of mineralization is influenced by many factors including environmental conditions (soil temperature, soil moisture, light levels, etc.), tillage practices (soil incorporation, depth of incorporation, timing of tillage, etc.), soil microorganism populations, and composition and particle size of the organic matter. To complicate matters, these factors also interact.

In general, mineralization will be slower at lower soil temperatures because the soil organisms involved are less active at lower temperatures. Mineralization is slower when soil is dry or waterlogged for the same reason. When organic nutrient sources, such as composts and manures, are not turned into soil and left on the soil surface, mineralization will be relatively slow due to drying. When the organic nutrient source is incorporated into the top 6 to 8 inches of soil, mineralization will occur more rapidly because this is the area of soil where most of the organisms involved in mineralization are. When the organic nutrient source is soil incorporated deeper than 8 inches, mineralization will occur more slowly because lower oxygen levels at deeper soil depths limit the number of organisms involved in mineralization.

Using Compost

Composts can be an important part of managing nutrients. In addition to adding nutrients to the soil, they can improve long-term soil quality. Composts are best when used in combination with other nutrient management strategies including green manures, other fertilizers, and crop rotations.

National Organic Standard Summary on Compost

Composted plant and animal materials can be incorporated into soil as necessary, provided the compost meets carbon to nitrogen (C:N) and temperature requirements. Compost used must have had an initial C:N ratio between 25:1 and 40:1. In addition, when using an in-vessel or static aerated pile system for composting, the pile must reach a temperature between 131°F and 170°F for a minimum of 3 days. If using a windrow system for generating compost, the pile temperature must be maintained between 131°F and 170°F for a minimum of 15 days and turned a minimum of five times during that time.

Nitrogen, Phosphorus, and Potassium in Compost

Nitrogen in compost is in two forms: the organic form and the inorganic form made up of ammonium and nitrate. Total nitrogen content can be determined by adding the organic and inorganic forms of nitrogen (organic nitrogen + ammonium nitrogen + nitrate nitrogen = total nitrogen). Total nitrogen will normally range from 0.5 to 2.5 percent (dry weight basis) in finished composts. The ammonium and nitrate forms are readily available for plant uptake. However, the organic form of nitrogen must be broken down through the process of mineralization into inorganic nitrogen for plant use (see Mineralization section for more information).

The rate of nitrogen mineralization is dependent on many factors (including, pH, depth of incorporation, compost quality and quantity, climate conditions, particle size, level of decomposition, soil microorganisms, C:N, etc.) and varies widely. Through research we know that mineralization rates vary between 10 and 50 percent a year. This means that in some years only 10 percent of the nitrogen applied through compost will be made available for plant uptake, while in other years 50 percent of the nitrogen will be made available. This rate depends on the compost as well as soil conditions; in general, compost with a low C:N ratio will mineralize at a faster rate. (For more information see next section.) Compost is most commonly applied based on the nitrogen requirement of the crop, although soils that are high in phosphorus should be limited to the phosphorus requirement. An estimation of the mineralization rate is necessary to calculate how much compost to apply. A conservative estimate is that 10 to 20 percent of the nitrogen will be available in a given year.

Composts also contain phosphorus, potassium, magnesium, and calcium. Plant availability of these nutrients in compost has not yet been established.

A typical compost might have an analysis of 1-0.7-1. Using 12.5 tons per acre of this compost applies 250 pounds of nitrogen, 175 pounds of phosphate, and 250 pounds of potassium. Additionally, magnesium and calcium will be added to the soil. Nutrient levels can quickly surpass optimum levels when using compost yearly. This is a problem for several reasons. Yields can be below optimum as a result of nutrient imbalances in the soil. Research has also shown that different weeds proliferate when certain nutrients are available in excess. Nitrogen and phosphorus buildup can also be an environmental hazard.

Carbon to Nitrogen Ratio (C:N)

The carbon to nitrogen ratio (C:N) may be used as an indicator of compost stability and nitrogen availability. Compost C:N ratios typically decrease during composting if the starting C:N ratio is >25 but may increase if starting C:N ratios are low (<15) and nitrogen is lost during the composting process. Composts with high C:N ratios (>30) will likely tie up (immobilize) nitrogen if applied to soil, while those with low C:N ratios (<20) will mineralize organic nitrogen into inorganic (plant-available) nitrogen.

Tips for Using Compost

1. Avoid the continuous use of compost or any single organic nutrient source containing more than one nutrient. Instead, use a variety of nutrient sources. This will help avoid reaching soil nutrient levels exceeding crop needs.
2. Use soil testing to keep track of soil nutrient levels. If levels exceed crop needs, avoid using compost. Instead, use a nutrient source that has no or minimal levels of the nutrient(s) in excess. Refer to Tables 2, 3, and 4 for options. One exception to this tip is that starter phosphorus may be needed for some crops when soils are cold in early spring, even when soil phosphorus levels exceed crop needs.
3. Use compost testing. Composts differ in their chemical analysis. By having it tested, it can be more accurately applied.
4. Calculate the amount of compost to apply. As noted in the Nitrogen, Phosphorus, and Potassium in Compost section, this is commonly based on the nitrogen needs of the crop unless phosphorus levels exceed crop needs. When phosphorus levels are high, calculate both phosphorus- and nitrogen-based application rates and use the lower of the two. This practice will help avoid overapplication and its associated costs: the cost of the compost, environmental costs, and loss of profits due to compromised plant health.
5. Incorporate compost in the soil. This will promote the mineralization process (see Mineralization section for more information) and minimize runoff and erosion losses.
6. If phosphorus levels exceed crop needs or it is suspected that nitrogen levels are high, minimize losses through erosion, runoff, and leaching. Environmental concerns develop when phosphorus and nitrogen reach bodies of water. Minimizing erosion by planting cover crops, using reduced tillage practices, or using grass waterways to catch and infiltrate runoff from a field can curtail movement of these nutrients.

Estimating How Much Compost to Apply Based on Crop Nitrogen Needs

Two basic methods for estimating compost application rates exist. Both methods require knowing the nitrogen content (the organic and ammonium nitrogen) of the compost. If the nitrogen content needs to be determined, compost analysis kits are available through your local Penn State Cooperative Extension office. The second piece of information needed is the nitrogen requirement of the crop to be grown. This information can be found on soil test results or in production guides such as the *Commercial Vegetable Production Recommendations* guide for Pennsylvania.

Method 1

Step 1: Determine the N content of the compost in pounds per ton.
The two values you'll need from your compost analysis report are organic nitrogen and the ammonium nitrogen (NH_4-N) from the "as is basis" column. If Penn State's Agricultural Analytical Services Laboratory performed the analysis, organic N and ammonium N will be given as a percentage. Convert organic nitrogen from percent to pounds per ton by multiplying by 20.

Organic nitrogen (%) = ___ x 20 = ___ lbs organic N/ton of compost

Ammonium N (%) = ___ x 20 = ___ lbs NH_4-N/ton of compost

Example:

Organic nitrogen (%) = 1.1 (from compost analysis report) x 20 = 22 lbs organic N/ton of compost

Ammonium N (%) = 0.16 (from compost analysis report) x 20 = 3.2 lbs NH_4-N/ton of compost

Step 2: Determine how much of N in a ton of compost will be available to the plants.
Organic N is converted into inorganic N for plant uptake through mineralization (see Mineralization section for more information). Commonly, mineralization rates between 10 and 20 percent are assumed. However, if conditions favor higher mineralization rates—for example, (1) if soil temperatures are high because of the use of black plastic, (2) soil moisture is high from irrigation and/or rainfall, (3) soil is frequently tilled, or (4) the organic matter content of the soil is high—consider assuming higher rates of mineralization. For this step multiply the amount of organic N in pounds per ton by an assumed mineralization rate. Add the amount of ammonium N in pounds per ton from step 1 to the result.

Organic nitrogen (lbs organic N/ton of compost determined in Step 1) ___ x ___ percent mineralization rate = ___ lbs available organic N/ton of compost

___ lbs available organic N/ton of compost +___ lbs NH_4-N/ton of compost (determined in Step 1) = ___ lbs available N/ton of compost

Example:

Organic nitrogen (lbs organic N/ton of compost) 22 x 0.20 (or 20%) percent mineralization rate = 4.4 lbs available organic N/ton of compost

4.4 lbs available organic N/ton of compost + 3.2 lbs NH_4-N/ton of compost = 7.6 lbs available N/ton of compost

Step 3: Determine the amount of compost to apply.
For this step first determine the nitrogen needs of the crop in pounds per acre. This information can be found on soil test reports or in production guides such as the *Commercial Vegetable Production Recommendations* guide for Pennsylvania. If you have residual nitrogen in the soil from previous nutrient applications or green manure crops, subtract that value from the recommended rate. Then, divide the remaining amount of nitrogen required by the pounds of available nitrogen per ton of compost determined in Step 2.

___ lbs N recommended/acre (from soil test report or production guide) minus any residual nitrogen ÷ ___ lbs available N/ton of compost (determined in Step 2) = ___ tons of compost to apply per acre

Example:

75 lbs N recommended/acre (assuming no residual nitrogen) ÷ 7.6 lbs available N/ton of compost = 9.9 tons of compost to apply per acre

If using a front-end loader or manure spreader with a scoop, figure out how many 5-gallon bucketfuls fit in the scoop, weigh a 5-gallon bucket of compost, and multiply to determine the weight of compost being applied per scoop.

The above method will have some built-in inaccuracy because it does not account for differences in weight due to how the compost is packed or moisture level. A second, more accurate method requires that the bulk density of the compost be determined.

Method 2

Bulk Density

This method is more accurate than the first method because it accounts for the changing moisture content of compost. It can be easier if you are using manure spreaders or front-end loaders because results are in pounds per cubic yard (lbs/yd^3). It requires determining the bulk density of the compost, which can be done in two ways. If using Penn State's Agricultural Analytical Services Laboratory to analyze compost, the lab can determine bulk density as an optional test at a current cost of $10.

Bulk density can also be determined before submitting the sample. This is more accurate than results from the lab because the lab uses less compost in its determination. The materials needed to determine the bulk density are a shovel, 5 gallon bucket and a scale (a bathroom scale will work). Fill the 5 gallon bucket half full, taking compost from various depths of the pile. Then drop the bucket 10 times from a height of about 6 inches. Fill the remaining portion of the bucket approximately half full and repeat the dropping process. Next, fill bucket to the brim and repeat the dropping process. Finally, fill bucket to the brim one more time and do not drop.

Once that is done weigh the bucket with the compost in it and record the weight.

Weight of compost and bucket = ___ lbs

Example:

Weight of compost and bucket = 40 lbs

Subtract 2 pounds (the weight of a typical bucket) from the weight above to obtain the net sample weight.

Weight of compost and bucket = ___ lbs – 2 lbs = ___ net lbs

Example:

Weight of compost and bucket = 40 lbs – 2 lbs = 38 net lbs

Next, multiply the net sample weight by 40 to convert to pounds per cubic yard.

___ net lbs x 40 = ___ lbs/yd^3 (bulk density)

Example:

38 net lbs x 40 = 1520 lbs/yd^3 (bulk density)

Lastly, insert the bulk density value on the compost submission form on the line that reads "producer-determined bulk density" (lb/yd^3).

When bulk density is determined, the compost analysis report will have a third column labeled "volume basis." This is the column to use for calculating how much compost to apply using Steps 1 and 2 below.

Step 1: Determine how much available nitrogen is in a ton of compost.
Multiply the amount of organic N by a mineralization rate. Then, add the amount of ammonium N.

Organic nitrogen (lbs organic N/yd^3 of compost from compost analysis report) ___ x percent mineralization rate (estimated based on environmental conditions; see Mineralization section) = ___ lbs estimated available organic N/yd^3 of compost

___ lbs available organic N/yd^3 of compost (calculated above) + ___ lbs NH4-N/yd^3 of compost (from compost analysis report) = ___ lbs available N/yd^3 of compost

Example:

Organic nitrogen (lbs organic N/yd^3 of compost) 16.7 x 0.20 (20%) percent mineralization rate = 3.34 lbs available organic N/yd^3 of compost

3.34 lbs available N/yd^3 of compost + 0.19 lbs NH4-N/yd^3 of compost = 3.53 lbs available N/yd^3 of compost

Step 2: Determine the amount of compost to apply.
To do this, take the nitrogen recommendation and divide it by the amount of available nitrogen in a cubic yard of compost. Nitrogen recommendations can be found on soil test results or in production guides such as the *Commercial Vegetable Production Recommendations* guide for Pennsylvania. If you have residual nitrogen in the soil from previous nutrient applications or green manure crops, subtract that value from the recommended rate. Then, divide the remaining amount of nitrogen required by the pounds of available nitrogen per cubic yard of compost.

___ lbs N recommended/acre (from soil test report or production guide) minus any residual nitrogen ÷ ___ lbs available N/yd^3 of compost (from Step 1) = ___ yd^3 of compost to apply per acre

Example:

75 lbs N recommended/acre (assuming no residual nitrogen) ÷ 3.53 lbs available N/yd^3 of compost = 21.2 yd^3 of compost to apply per acre

Estimating Residual Nitrogen from Compost

Since not all the organic nitrogen in compost is mineralized in the year it is applied to the soil (see Mineralization section for more information), nitrogen will made available to plants in subsequent years. Accounting for this residual nitrogen can decrease the amount of nitrogen applied in the subsequent year, saving money and helping avoid overapplication of nutrients.

Step 1: Estimate how much organic nitrogen was used in the year compost was applied.

Take the pounds of organic nitrogen in a ton or cubic yard of compost and multiply it by the total number of tons or cubic yards applied. Then, multiply the result by the mineralization rate used when originally calculating how much compost to apply.

___ organic N lbs/ton or yd^3 x ___ tons or yd^3 of compost applied = ___ lbs organic N applied

___ lbs organic N applied x ___ mineralization rate = ___ lbs organic N available in the year the compost was applied

Example:

16.7 lbs organic N/yd^3 x 21.2 yd^3 of compost applied = 354 lbs organic N applied

354 lbs organic N applied x 0.20 (or 20%) mineralization rate = 70.8 lbs organic N available in the year it was applied

Step 2: Determine how much organic nitrogen is left in the soil.

Take the pounds of organic nitrogen applied (determined in Step 1) and subtract the total pounds of organic nitrogen available in the year the compost was applied (determined in Step 1). The result is the amount of organic nitrogen left in the soil that can undergo mineralization and be available for plant uptake in the year after the compost was originally applied.

___ lbs organic N applied (determined in Step 1) – ___ lbs organic N available in the year it was applied (determined in Step 1) = ___ organic N left in the soil

Example

354 lbs organic N applied – 70.8 lbs organic N available in the year it was applied = 283.2 lbs organic N left in the soil

Step 3: Finally, assume a mineralization rate for the organic nitrogen left in the soil.

For this step, take the result of Step 2 and multiply it by a 10 percent mineralization rate. This final result is the amount of residual nitrogen available the year after the compost was applied. This value can be subtracted from nitrogen application recommendations.

___ lbs organic N left in the soil x 0.10 (or 10%) = ___ lbs residual nitrogen

Example

283.2 lbs organic N left in the soil x 0.10 (or 10%) = 28.3 lbs residual nitrogen

Using Manure

Tables listing the nutrient contents of different manures are available; however, nutrient content varies depending on several factors, including the feed the source animal was provided, presence of bedding in the manure, and manure handling. Also, nutrient availability changes as the manure ages. Therefore, it is recommended that manures be tested for their nutrient contents. Manure is applied based on the nitrogen needs of the crop. Fact sheets are available through Penn State Cooperative Extension with detailed calculations for determining application rates for manures (for example, *Agronomy Facts 55: Estimating Manure Application Rates*).

Much of the nitrogen contained in fresh manures is in the form of ammonia or ammonium, which can be quickly lost to the atmosphere through volitalization. To avoid this nitrogen loss, raw manures should be soil incorporated when possible. Applying manure well in advance of production—for example, in the fall or as mandated for organic growers (see section below)—is recommended.

National Organic Standard Summary of Manure Use

According to the national organic standards, raw animal manures can be used when needed on fields planted with crops not intended for human consumption, such as green manures or cover crops. When raw manures are used on fields that are planted in crops for human consumption with the edible part of the crop not in contact with the soil (e.g., staked tomatoes, peppers), it must be soil incorporated a minimum of 90 days before harvest. When raw manures are used on fields that are planted in a crop for human consumption with the edible part of the crop in contact with the soil (e.g., matted-row strawberries, melons), it must be soil incorporated a minimum of 120 days before harvest. The use of sewage sludge is prohibited in certified organic production.

Additional Sources for Information

The following publications and Web sites are suggested for those who would like more information on using organic nutrient sources. Penn State publications can be obtained from through your local Penn State Cooperative Extension office, on the Web sites below, or by contacting the Publications Distribution Center at 112 Agricultural Administration Building, University Park, PA 16802; phone: 877-345-0691.

Penn State Cooperative Extension Publications

Arrington, K., C. Abdalla, D. Beegle, R. Graves, and K. Saacke Blunk. *Nutrient Budgets for Pennsylvania Cropland: What Do They Reveal and How Can They Be Used?* University Park: The Pennsylvania State University, 2007. **pubs.cas.psu.edu/FreePubs/pdfs/ua442.pdf**

Beegle, D. *Agronomy Facts 55: Estimating Manure Application Rates.* University Park: The Pennsylvania State University, 1997. **pubs.cas.psu.edu/FreePubs/pdfs/uc151.pdf**

———. *Agronomy Facts 60: Nutrient Management Planning: An Overview.* University Park: The Pennsylvania State University, 2003. **pubs.cas.psu.edu/FreePubs/pdfs/uc156.pdf**

Orzolek, M. D., E. Sánchez, W. J. Lamont, T. Elkner, K. Demchak, G. Lin, J. M. Halbrendt, B. Gugino, S. J. Fleischer, L. LaBorde, K. Hoffman, and G. J. San Julian. *2009 Commercial Vegetable Production Recommendations—Pennsylvania.* University Park: The Pennsylvania State University, 2009. Available for $16.

Other Publications and Web Sites

Clark, A. *Managing Cover Crops Profitably.* 3rd ed. Beltsville, Md.: Sustainable Agriculture Network, 2007. Available for download from **www.sare.org/publications/covercrops/covercrops.pdf**. May also be purchased for $19 from Sustainable Agriculture Publications, PO Box 753, Waldorf, MD 20604-0753; phone: 301-374-9696; **www.sare.org/publications/order.htm**.

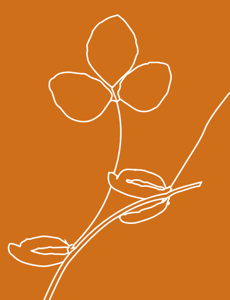
Dougherty, M., ed. *Field Guide to On-Farm Composting*. Ithaca, N. Y.: NRAES Cooperative Extension, 1999. Available for $14 from NRAES Cooperative Extension, PO Box 4557, Ithaca, NY 14852-4557; phone: 607-255-7654; **www.nraes.org**.

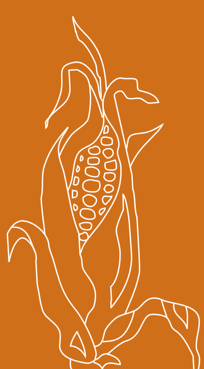
Organic Vegetable Production. Ithaca, N.Y.: NRAES Cooperative Extension, 2004. Available for $28 from NRAES Cooperative Extension, PO Box 4557, Ithaca, NY 14852-4557; phone: 607-255-7654; **www.nraes.org**.

Rynk, R., ed. *On-Farm Composting Handbook*. Ithaca, N.Y.: NRAES Cooperative Extension, 1992. Available for $25 from NRAES Cooperative Extension, PO Box 4557, Ithaca, N. Y. 14852-4557; phone: 607-255-7654; **www.nraes.org**.

Sarrantonio, M. *Northeast Cover Crop Handbook*. Kutztown, Pa.: Rodale Institute,1994. Available for $16.95 from the Rodale Institute Bookstore, 611 Siegfriedale Road, Kutztown, Pa. 19530; phone: 610-683-6009; **www.rodaleinstitutestore.org**.

USDA Agricultural Marketing Service National Organic Program: **www.ams.usda.gov/nop**





Prepared by E. S. Sánchez, associate professor of horticultural systems management, and T. L. Richard, associate professor of agricultural and biological engineering.

Building on *Soil Testing for the Organic Gardener* (The Pennsylvania State University, 1972) by R. F. Fletcher and P. A. Ferretti.

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Where Do I Put My Crops? Planning a Crop Rotation from the Start

I like to do my initial crop plan in the winter. Planning takes time. It may be a part of farming that many of us avoid. But, I find that having a good plan, laid out in an easy to read map makes it possible to quickly do what needs to be done during the season, know what my contingency plans are, and the avoid major problems with pests, weeds and fertility that are more common with haphazard plantings.

The steps below are a summary of two great publications *Crop Rotations on Organic Farms* and chapter 7 from *Sustainable Vegetable Production from Start Up to Market* [1, 2]. *Growing for Market* also has a number of articles on crop planning steps, techniques and software. See references [3, 4]. I suggest you take some time with these publications and then use the following steps when you sit down to make your crop plan.

1. **Write down your goals.** Describe what are you trying to achieve with your rotation? See table 1 for a list of common goals identified by experienced farmers.
2. **Prioritize your goals.** Which goals are most important for your farm?
3. **List crops you plan to grow and how much you plan to grow.**
4. **Create rotational groups.** Group crops by family, planting arrangement, nutrient needs, timing or other important qualities. See table 2 and table 3.
5. **Check for excessive acreage of one family.**
6. **Make a map of your farm or garden.** Make sure that the map is drawn to scale. It helps to download a real map of your farm with soil types from web soil survey with your soil types that you can overlay field drawings onto. They have a function where you can measure field sizes on their map. See reference [5].
7. **Divide your farm or garden into equal size rotational units.** It is much easier to plan your rotation in terms of fields of the same size or uniform strips within fields. For example divide the farm into 2 acre fields or into beds 300 foot long by 5 feet wide. The size of the units will depend on the size of your farm and what you can 'get your head around.' The size of your rotational units typically matches the smallest area planted to a single crop or rotational group.
8. **Define the land area (rotational units) needed for each grouping of crops.** For example, you may devote several units to certain crop, like pumpkins, and only one unit to other crops, like carrots.
9. **Identify conditions on your farm that will affect which crops are grown where on the farm.** Few farms or even gardens have uniform conditions in each part of the farm. Some fields may be wet. Some fields may dry out and warm up earlier in the spring making them good fields for early planting. Some fields may have problems with a diseases or pests. Note these conditions on your field map
10. **Make multiple copies of your farm map.**
11. **Using copies of the farm map compare possible rotations.** Keep in mind:
    a. Timing of field operations and equipment required for different rotational units.
    b. Inclusion of cover crops and their affect on subsequent crops.
    c. Disease history and how long the rotation must be between crops/ groups to avoid/ ameliorate disease.
    d. Inclusion of fallow periods, rotation between weed prone and competitive crops and rotation between crops grown in different seasons for weed management.
    e. Rotation in time and space of susceptible crops to keep insect pests from returning to crops the next year or moving from crop to crop in the field.
12. **Alternatively, use a Field Conditions/ Field Futures Worktable or a Fields table with a time axis.** See reference [2] for detailed worktables. See table 4 for 'Field Table with a Time Axis' blank forms.

Table 1. Common Goals for Crop Rotation

1. Conserve and build organic matter	2. Add nitrogen
3. Control diseases	4. Reduce labor
5. Reduce weed pressure	6. Minimize off farm inputs
7. Increase profits	8. Capture solar energy
9. Have a diverse product line	10. Economic stability
	11. Control insects

From Sidebar 2.8 'Crop Rotation on Organic Farms a Planning Manual' – Mohler.

Table 2. Crop Features That May be the Basis for Rotation Groups.

Crop Feature	**Examples**
Botanical Family	Crucifers, cucurbits, nightshades
Harvested Anatomical Structure	Roots, leaves, fruits, grains
Planting arrangement	Multiple rows on raised beds, narrow single rows, wide row spacing
Cultivation practices	Hilled crops, wheel hoed crops, mulched crops
Timing of planting and harvest	Early, mid, late season; multiple
Nutrient demand	Heavy, med, light
Cultural practices	Drip irrigation, overhead, row cover
Pest complex	Fenced for deer, sprayed for colorado potato beetle . . . ..

From Table 7.1 'Sustainable Vegetable Production from Start–up to Market' – Grubinger.

Where Do I Put My Crops? Planning a Crop Rotation from the Start

Table 3. Example Crop Grouping

Family	Crop	Planting Date**	Weeks in Field	N Needs lb/A	Rows/ 4' Bed (5' Center)	Cultural Practices	Weed Competition	Seedbed Required
Beet	**Beets**	Espr	7 to 9	130	3	d	mod	fine
Beet	**Spinach**	Espr	4 to 6	130	3	d	mod	fine
Beet	**Swiss chard**	Espr	7 to 8	90	3	d	mod	fine
Carrot	**Carrots**	Espr	10 to 12	90	4	d	low	fine
Crucifer	**Arugula**	Espr	4 to 6	90	4	d	low	fine
Crucifer	**Broccoli**	Espr	7 to 9	130	2	s	mod	med
Crucifer	**Cabbage**	Espr	10 to 12	130	2	s	mod	med
Crucifer	**Cauliflower**	Espr	10 to 12	130	2	s	mod	med
Crucifer	**Collards**	Espr	10 to 12	130	2	s	mod	med
Crucifer	**Kale**	Espr	7 to 9	130	2	d	mod	med
Crucifer	**Mustard greens**	Espr	4 to 6	45	3	d	low	fine
Crucifer	**Pac choi/ tat soi etc**	Espr	7 to 9	45	4	d	low	fine
Crucifer	**Radishes**	Espr	4 to 6	45	4	d	low	med
Crucifer	**Turnips**	Espr	4 to 6	45	4	d	mod	fine
Legume	**Peas**	Espr	7 to 9	0	2	d	low	med
Lettuce	**Lettuce**	Espr	4 to 6	45	3	p/d	mod	med
Lily	**Green onions**	Espr	4 to 6	45	4	d	low	fine
Curcubit	**Cantaloupes**	Sum	10 to 12	90	1	p	high	med
Curcubit	**Cucumbers**	Lspr	7 to 9	90	1	p	mod	med
Curcubit	**Summer squash**	Lspr	7 to 9	90	1	p	high	med
Curcubit	**Winter Squash**	Fall			1	p	high	coarse
Curcubit	**Watermelons**	Sum	10 to 12	45	1	p	high	med
Lamiaceae	**Basil**	Sum	10 to 12	45	3	p	low	med
Grass	**Sweet corn**	Sum	10 to 12	130	2	d	high	med
Legume	**Snap beans**	Lspr	7 to 9	0	2	d	mod	med
Legume	**Southern peas**	Sum	7 to 9	0	2	d	mod	med
Mallow	**Okra**	Sum	10 to 12	90	1	p	low	fine
Nightshade	**Bell peppers**	Sum	7 to 9	90	2	p	mod	med
Nightshade	**Eggplant**	Sum	10 to 12	90	2	p	mod	med
Nightshade	**Tomatoes**	Sum	7 to 9	130	1	p	mod	med

**Sum = Summer, Lspr = Late spring, Espr= Early Spring.

Table 4. Field Map with a Time Axis

Field Name	
Block Number	
March	6
	13
	20
	27
April	3
	10
	17
	24
May	1
	8
	15
	22
	29
June	5
	12
	19
	26
July	3
	10
	17
	24
	31
August	7
	14
	21
	28
September	4
	11
	18
	25
October	2
	9
	16
	23
	30
November	6
	13
	20
	27
December	4
	11
	18
	25
January	1
	8
	15
	22
	29
February	5
	12
	19
	26

Where Do I Put My Crops? Planning a Crop Rotation from the Start

1. Grubinger, V.P., *Sustainable Vegetable Production from Start Up to Market*. 1999, Ithica, New York: National Resource Agricultural Engineering Service Cooperative Extension.
2. Mohler, C.L. and J.S. E., eds. *Crop Rotation on Organic Farms - A Planning Manual*. 2009, Natural Resource Agricultural and Engineering Service NRAES Cooperative Extension: Ithica, NY. http://www.sare.org/publications/croprotation/croprotation.pdf.
3. Dawling, P., ed. *How to Plan Crop Rotations*. Growing for Market. 2007: Fairplains Publishing Incorporated.
4. Volk, J., ed. *Mapping crops on a spreadsheet*. Growing for Market. 2010: Fairplains Publishing Incorporated.
5. *Web Soil Survey*. Available from: <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>.

Additional Resources:

Kroeck, S. 2004. Soil Resiliency and Health: Crop Rotation and Cover Cropping on the Organic Farm. Northeast Organic Farming Association.

Jeavons, J. 2006. How to Grow More Vegetables than you ever thought possible on less land than you can imagine, 7th edition. Ecology Action. Willits, CA.

Eliot Coleman, The New Organic Grower. Gardeners Supply. Harborside, ME.

Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension. Reviewed by Lee Rinehart, Pennsylvania Certified Organic and Elsa Sanchez, Penn State Department of Horticulture. *Last updated - November 2011*.

Selecting the Right Seeding and Transplanting Strategies

Seeding Goals

- Optimize soil-seed contact
- Precise seed depth placement for optimum soil temperature, moisture emergence
- Accurate and consistent spacing for a uniform stand and less time thinning
- Limited time wrestling with equipment
- Few returns to the field to fill in misses or dead plants

Choose Equipment that Fits your Scale, Financial Constraints and Style

Small Farm on a Budget. Most small farms start out using a push "plate" seeder. Some people may argue that hand seeding is more accurate and they don't want to go back and thin. But, a seeder saves enormous amounts of time, and precise seed placement saves seed. The *Earthway* seeder generally is the most common and least expensive [2]. It has a interchangeable notched plate that rotates inside of the seeder picking up individual seeds and dropping them through a hole in the side of the hopper.

Hand transplanting can be fast and efficient for the small, diverse farm. If you choose hand transplanting, make sure you work on your hand transplanting technique for efficiency and ergonomics. Some farms will have one person with a good eye place plants and another come along quickly and tuck them in. Others have a favorite tool such as a Japanese transplanting hoe or ***Hori-Hori*** that saves their wrists.

Small-scale, Adding Efficiency. In that delicate balance of efficiency, precision and price tag, many farmers choose a more precise push seeder after they are better established. Others still swear by the light-weight *Earthway* (see equipment reviews). These seeders may have different cogs or plates with a greater diversity of hole sizes/spacing to allow you to change the seed spacing. *Planet Jr*., *Jang AP-1* and *Johnny's European Seeder* are common seeders to consider.

Medium to Large Farm. Four acres seems to be the breaking point where most farms go to tractor mounted seeders and transplanters. Tractor mounted seeders (like most push seeders)

"Speed is no different with the transplanter. The main difference is the water. It is also much easier on your body."

- John Good, Quiet Creek Farm, Kutztown, PA.

Seeding lettuce next to tomatoes at The Seed Farm, Vera Cruz PA.
Photo J. Zehr.

Japanese transplanting hoe.
Photo S. Tianna DuPont, Penn State University.

control seed singulation and spacing with a plate, a punched belt, seed cups or vacuum systems [4]. The difference from a push seeder is the time saved seeding over a large area. The trade off is that they can take longer to set up. But once you have them set up, you can plant large areas faster than you can walk (unless conditions are not suitable and you have to stop constantly to unclog the equipment in wet or cloddy conditions). There are many types of seeders. Reviewed in this publication include the *Planet Jr.* and the *Spyder Seeder*.

Time for a mechanical transplanter. Mechanical transplanters might not be faster than hand transplanting for the first hour or so, but as your back and quads start to hurt from squatting and stooping, you slow down. Water wheel transplanters are favorites these days because water delivered into the holes where transplants are set reduces transplanting stress and saves you time watering.

Desirable features of a good one row push seeder:

- Easy to push in a straight line.
- Precise and even seed placement.
- Allows accurate depth adjustment.
- Easy to fill and empty.
- Flexible and adaptable.
- Visible seed level and seed drop.
- Has a dependable row marker.

Elliot Coleman [1]

Planting Strategies to Make the Rest of Your Job Easier

Straight rows. You might think the pursuit of the perfectly straight row is merely a form of farmer pride, but transplanting or seeding in straight rows is essential, not only for the tractor scale farm, but smaller scales as well. My first farmer mentor let me learn the hard way. While learning to drive tractor and transplant, I planted a very wavy bed. When I came back to cultivate, it was impossible not to take out plants, even driving slowly. If you plan to hoe, you have more flexibility, but it is much faster to go quickly down evenly spaced straight rows with one pass of the hoe than working your way around uneven, scraggly ones.

Markers. There are a number of ways to mark your rows and keep them evenly spaced. Most push seeders will have an adjustable row marker. Some people stretch string. For transplants on the small scale, some use a row marking rake or a push seeder without seeds [5]. I am interested to try the *rolling dibbler* designed by Healthy Farmers, Healthy Profits Project in Wisconsin. It consists of a roller with plastic cups attached to make divots in the soil at the desired spacing both in-row and between rows [6]. Josh Volk describes additional, more sturdy ways to make markers. See reference [9]. Another farmer I know marks his rows for seeding with the Williams Tool System (Market Farm Implements) tractor mounted cultivator.

"Labor and time savings are phenomenal (with our water wheel transplanter). We can plant 2.5 acres in one, albeit long, day with just two people -- one to drive and one to transplant -- with our one-row transplanter. This frees us for the myriad other tasks that time of year -- tending to weeding, for example."

Claudia Ferrell [3]

Spacing for Good Weed Management. I can't emphasize enough how important it is to set up your plant spacing for seeding and transplanting in a way that facilitates your weed management later. For example, a very common set-up is beds on 5 foot (60-inch) centers. This gives you 48 inches of growing space and 12 inches of walking area. If you are on a smaller scale and the tools you plan to manage weeds with are an 8-inch wheel hoe and a 5-inch hula hoe, then your densest planted crops should have at least 6 inches of space between to hoe. If you are using a tractor, the standard is a 3-2-1 system where your largest spaced crops are on 60-inch centers, your medium size crops are 28 inches apart and smaller crops are 14 inches apart [7]. Choose a few plant spacings that work with your equipment and stick to them, this saves monkeying around moving sweeps or trying to find a narrower hoe later.

Calibration. No matter which seeder you use, it is worth the time to check and make sure it is functioning. I have made the mistake of not checking, usually when I hurry, and then finding out later that there was a problem. This can be heart breaking when you have missed a window for a succession of carrots or end up with such a patchy planting of spinach it is not worth the time to cultivate it. Common problems are cob-webs in the seed tubes of tractor mounted seeders, plates not picking up seed or grinding it, or choosing the wrong setting. Generally, I calibrate by picking up the seeder, turning the drive wheel a certain number of times which correlate with the distance it would travel in the field and counting or weighing the seed that comes out. If I don't get any seeds, I know there is a real problem. On a seeder that you can change belts or gears to change the spacing, calibration can save a lot of seed and time thinning later.

Equipment Reviews

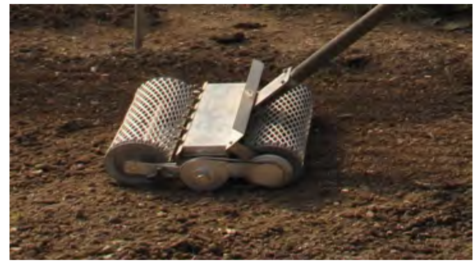
The following equipment reviews are included to give new producers a taste of the benefits and drawbacks of various seeding and transplanting equipment. Equipment choices tend to be very particular to the farm and the farmer and the following comments are not exhaustive or meant to promote the use of a particular brand or company. For further reviews see Farm Profiles.

Seeding Equipment Comparison. The Seed Farm, Lehigh County's Agricultural Incubator Project, trialed small-scale seeding and transplanting equipment in their two-acre demonstration and training garden during the 2010 season. They trialed the following equipment: Johnny's six row seeder, Earthway push seeder, the Seed Stick Planter and the Glaser pull seeder. The seeders were used to direct-seed four crops: carrots (Johnny's six row seeder, Earthway and Glaser), spinach (Johnny's six row seeder and Earthway), arugula (Johnny's six row seeder, Earthway and Glaser), and cucumbers (Earthway and Seed Stick). All five Seed Farm ap-prentices were trained to use the different seeders. Their con-clusion was that the Earthway was the most versatile of the

Rolling dibble marker for easy transplant spacing.
B. Meyer, University of Wisconsin.

Spinach planted with the Johnny's six row seeder. The six row seeder performs well when working with finely-prepared beds, but the beds at The Seed Farm were not tilled before planting.
S. Runkel, The Seed Farm,
Vera Cruz, PA.

seeders, but for certain crops, the other seeders were useful. In particular, the Glaser was much better than the Earthway for planting arugula and other brassicas because it did not grind up the seed. The Johnny's six row seeder was more efficient than the Earthway for planting salad greens (arugula and spinach), but it only worked in very finely prepared soil. The apprentices did not find the Seed Stick useful for cucumbers because the seed tended to get clogged in the seeder. However, it was useful for slightly larger seeds like summer squash and winter squash.



Johnny's Six Row Seeder
Photo S. Tianna DuPont,
Penn State University.

Johnny's Six Row Seeder. The six row seeder is designed for salad mix and baby green production. Up to six rows can be planted at once with 2-¼" spacing. Growers can use it on well-prepared beds for the consistent placement of densely planted seeds. It can plant many seeds accurately for intense high tunnel production. However, this seeder does not seem to work well in rocky or clumpy field soil. Another concern is there is not an easy way to mark when you have the seeder calibrated, so you end up having to fiddle with it each time you use it. The six row seeder is only suitable for small seeded crops (under beet size) and it does not always press seed into the soil, which requires beds to be rolled following seeding.

Earthway Seeder. The Earthway generally gives precise seed placement, allows for depth adjustment and is easy to fill and handle. Nicole Shelly of Gotschell Farm in Emmaus, Pennsylvania, says *"I can use it on all my crops with reasonable accuracy and reliability. I choose it because it was economical and had a good/decent reputation."* I like that it is lightweight and easy to handle. However, if your farm has heavy or rocky soil, such a light seeder may be difficult to use. Another common problem is small seeds getting stuck behind the small brassica seed plate, crushing seed and preventing the seeder from picking up and depositing seed correctly. Growers recommend a number of remedies from reinforcing plates to simply buying new ones. Elliot Coleman redrills the holes at a blunter angle, so there is not as much slope to force the seeds behind the plate [1]. The plates may also develop a static charge where seeds stick to the plate. The manufacturer recommends that you "coat the plate with liquid soap and let it dry without rinsing [8]."

Four-Row, Pinpoint Seeder. Daniel Matz from Keepsake Farm and Dairy in Bath, Pennsylvania, uses the four-row, pinpoint seeder because *"it is insanely quick,"* simple to adjust and operate and seems sturdy. Like any pull or push seeder, it can get stuck and not drop a seed, but since you can easily tell if the wheel tines are spinning or not, you can just go over the part where it stopped turning. It plants lettuce and other greens very closely (2-¼" spacing with all of hoppers full) or can plant at a wider spacing by filling fewer hoppers. You control the seed depth by angling the handle lower or higher, "which is easy, but it can get a little awkward to hold at a low angle, especially as you draw it nearer to your body." There are a few limiting factors. *"The hoppers don't have a huge capacity, so you have to keep extra seed handy and watch for the levels to go down -- get distracted and you might miss where you stopped planting. There's no cover for the hoppers so water can get in if it's raining or you're in a drippy greenhouse."* It is also only suitable for small seed (under beet size).

API Clean Seeder (Jang) is a push seeder available from Mechanical Transplanter and others. Josh Volk from Slow Hand Farm in Oregon says, "it is an excellent upgrade from the Earthway. It has much more control in metering and heavier, wider construction that makes it work better in heavier conditions."

Spyder Seeder. Ben Shute from Hearty Roots Farm in Tivoli, New York, explains his Spyder Seeder. *"I decided not to buy one of the pre-built seeders (not easily available in the U.S.), but to* *buy the main parts of the Spyder (hopper, controller, meterer) and build my own frame for it, so I could use it mounted to the belly of my Allis Chalmers G tractor (the pre-built units are 3 point hitch units to mount behind a utility tractor). Also it's cheaper that way, but still not cheap, the parts alone cost me $3,000. I bought them from Sutton Ag in California."*

The unique part of the *Spyder* is the seed metering/delivery system, not the parts that deal with the soil. That is, the shoes/openers, press wheels, etc., are all just standard parts that I used, not Spyder-specific. The Spyder parts are a hopper that can feed between 1 to 6 rows using an electric motor that spins a dry sponge, gently pushing the seeds into spouts, and a controller to control the speed of the motor. It can deal with almost all of the types of seeds Ben uses on his vegetable farm, except corn and beans (too big). The rounder the seed, the more consistent the metering, so Ben uses pelleted parsnip and carrot seeds because that works better. It's a huge advantage that just one hopper can feed up to six rows, because with other seeders (Planet Jr., etc.) you need one hopper per row, which means filling/emptying every hopper to change varieties, and you need more seed to "prime" each unit. With this, you don't need much to prime the unit, and it's super quick to change varieties.

An adjustable little dial controls the speed of the electric motor that meters out the seeds. It's not as accurate as a vacuum seeder, which can place a seed precisely; but it gives you control over how fast the "dribble" of seeds is. So, not perfect spacing, but very controllable.

Parts seem more expensive than they should be, given what the thing is made of, but still worth it to Ben. Although it can seed from 1 to 6 rows, it's not quick and easy to change the number of rows you're seeding; you either need a separate piece which would take a couple of minutes to change or you need to "hack" it and just creatively plug off certain rows, but that's not an ideal solution.

For additional discussion of seeders and transplanters see articles by Josh Volk, Slow Hand Farm, references 10 and 11, Sustainable Vegetable Production reference 4, and Equipment and Tools for Small Scale Intensive Production reference 12.

For additional reviews see "Farmer Profiles" on extension.psu.edu/start-farming.

References

1. Coleman, E., *The New Organic Grower*. 1995, White River Junction, VT: Chelsea Green Publishing Co.
2. Shute, B., *Equipment Scenarios.* Hearty Roots Farm available at http://extension.psu.edu/start-farming, 2010.
3. Ferrell, C., *Growing Transplants for a Mechanical Transplanter.* Growing for Market, 2003.
4. Grubinger, V.P., *Sustainable Vegetable Production from Start Up to Market*. 1999, Ithaca, New York: National Resource Agricultural Engineering Service Cooperative Extension.
5. Dawling, P., ed. *A Growers Guide to Transplanting Vegetables*. Growing for Market. 2007, Fairplain Publications, Inc.
6. Newenhouse, A., et al., *A rolling dibble marker for easy transplant spacing.* University of Wisconsin, Madison; Healthy Farmers, Healthy Profits Project, 2000.
7. Runkel, S., *Personal Communication*. 2011, The Seed Farm: Vera Cruz, PA.
8. SSAWG. *Network Discussion Summary: Topic: Seeder*. http://www.ssawg.org/OFN-seeder.html.
9. Volk, J., *Dibblers Make Planting Easier, Neater.* 2009, Growing for Market; Fairplain Publications.
10. Volk, J., *Tools that Make Direct Seeding Easier.* 2009, Growing for Market; Fairplain Publications.
11. Volk, J., *Tips for Buying the Best Mechanical Transplanter.* 2009, Growing for Market; Fairplain Publications.
12. Pressman, A. 2011. Equipment & Tools for Small Scale Intensive Crop Production. 2011, NCAT.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension. Reviewed by Josh Volk, Slow Hand Farm, Lee Rinehart, Pennsylvania Certified Organic, Elsa Sanchez, Penn State Department of Horticulture. Last updated November 2011.

Charlestown Farm, Phoenixville, PA Seeding and Transplanting

Bill and Liz Anderson shared the seeding and trasplanting techniques they use on Charlestown Farm this spring. Working with their farm manager, Melissa Ingaglio, and 5 apprentices they grow produce on 40 acres near Phoenixville,Chester County, PA. Their farm feeds a 150 member CSA and they sell at the Phoenixville Farmers Market. Unfortunately, the soil was too wet while I was there for them to demo their seeding and transplanting equipment. But, they were kind enough to describe many of their practices.

Direct Seeding

The Seeder. Melissa direct seeds all large seeded crops using a hand push Planet Junior seeder. In fact, this is their preferred seeder for all of their direct seeding. In general, all greens (except spinach and swiss chard), peas, corn and root crops are direct seeded. They have a tractor mounted Planet Junior, but since they are often planting half sections of many different crops, it is not worth the time to prep and change the larger equipment.

The Planet Junior is heavy and difficult to manage until you get used to it, but it is much more precise than the Earthway Seeder they used to use. Melissa had a few complaints about the Earthway Seeder. Not only is it difficult to replace the plastic parts when they break, it does not always spin and can grind up your seed. "There is no going back if you miss an entire planting of early carrots (due to a bad seeding)."

Soil Prep depends on what size the seed is and how fussy the crop, which equipment and sequence Melissa uses to prep the field. Last year they bought a roll over plow (moldboard) that they use to integrate cover crops. First they mow the cover crop. Then they plow and disc. Sometimes they use the Williams Tool System (cultivator) or a rotory hoe to level the bed further and make a finer seedbed. They are thinking about getting a cultipacker to do this more efficiently. For very fine seeds like carrots they do use a rototiller as the last step before planting.

This system already saves them a lot of time and reduces how many times they pass over the field and disturb the soil compared to their old system. Without the roll over plow they had to mow, chisel plow and then disc 3 times with a week in between to create a decent seed bed.

Transplanting

At Charlestown they use a waterwheel transplanter for as much of their transplanting as they can. A water wheel transplanter has a large tank which feeds water into a rotating wheel. The wheel has teeth that punch into the ground at a set spacing. Each tooth has a hole which leaks water into the depression the tooth forms as it rotates, giving the transplant a nice muddy hole to start its outside life in. This does two main things. It helps reduce transplant shock and gives you leeway of a couple of days before it needs to rain or you need to turn the irrigation on. Two people sit on the back of the transplanter to place the plants in the holes made by the transplanter.

Melissa adjusting the transplanter seats for a shorter person.

The only critique that Melissa and the apprentices have is that the wheels on the water wheel can be very difficult and heavy to get on and off of the tranplanter. Since you have to change wheels every time you plant a crop with a different spacing this can be onerous.

An interesting use that they have found for the water wheel transplanter is to use it for planting potatoes. They just drop the potato pieces into the holes formed by the transplanter and then use hilling discs to cover the seed.

Tomatoes are transplanted by hand if the field is too wet to get in with a tractor.

Plastic Mulch

They transplant into plastic mulch for many crops. The crops grow faster in the warmer soils created by the mulch and of course the labor savings is significant. They use a plastic layer from ‘Rainflo’ a company in Lancaster County. One tip that Melissa gave me is that on a slope you need to adjust one of the hillers to be deeper otherwise the plastic will come up later.

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, 2010.

Quiet Creek CSA, Kutztown PA

Seeding and Transplanting

John and Aimee Good run Quiet Creek Farm, a certified organic CSA raising vegetables, berries, flowers, and herbs for 200 members. The farm is located on 8 acres of land leased from the Rodale Institute in Kutztown, PA. After I finished admiring tomato transplants in the caterpillar tunnel that already have green fruit in mid May, John was kind enough to take a few minutes out of his morning and talk to me about their seeding and transplanting techniques.

Aimee explains the Planet Junior to interns at a SAITA workshop.

Direct Seeding

The Seeder. John and Aimee use a Planet Junior, a European push seeder, for all of their direct seeded crops. John is not a fan of the Earthway push seeder that is the other common cheaper alternative. The Earthway is just not as precise and often does not work, according to John. Although the Plant-it-Junior may seem steep at over $600 "You can use it for everything" he says.

The Planet Junior has three plates with 32 different size holes. Usually to adjust the planter for the seed you are going to use all you have to do is spin the plate. For example they were able to use the same plate for everything in the early field we were looking at – beets, spinach, lettuce mix, arugula. . . . The trick comes when you have to switch plates. In order to get to the plate the hopper must be removed and the whole thing tends to fall apart when you are not used to using it. John admits the planter can be a little heavy and unwieldy at times. But they feel the advantages outweigh the disadvantages. Another plus to the Planet Junior that John mentioned was the spreader shoe. Instead of releasing the seed in a thin line the spreader shoe cascades the seed across a 2" wide strip.

At one of the farms they worked on, they had used a tractor mounted Planet Junior. But, it does not seem necessary for their scale. With 8 acres most of their beds are 250 feet long – short work with a push seeder. You can switch out seed easily by pouring it from the hopper and keep going. In contrast with a tractor mounted seeder, you would have to drive back to the truck, dump the hoppers, and add more seed before you planted the next crop. Since they only have one tractor, it would create competition for tractor time. With the push seeder they can easily delegate seeding to someone else. John also related how, at a friend's farm, using the Planet Junior tractor mounted seeder has become a two person job. They don't feel the seeder is consistent enough to work on its own, so they have to have someone walking to make sure seed if flowing.

They are considering getting another push seeder. Johnny's Selected Seeds recently came out with a "European Push Seeder" that is designed very similarly to the Planet Junior. It is also a three plate system, but the plates are easier to access. The machine is also lighter and less expensive at around $300.

Lettuce mix direct seeded into small furrows made by the Williams Tools System cultivating teeth used as row markers.

Preparing the seedbed

The Rodale Institute, their neighbor and landlord, has large tractors and equipment. Currently, it is most cost effective to have Rodale use the moldboard plow for primary tillage and cover crop incorporation. Then John discs. One great strategy that John shared is how he uses the William's Tool system to make furrows. The furrows act as row markers. Because all the markers are on the same bar if the tractor swerves slightly all the swerves are together, maintaining equal cultivation critical for good weed control. "Weeds will determine how well you can do anything," John says. The little furrow the plants are then seeded into can be good and bad. It can help funnel water to where the seeds are germinating which is nice if it is a little dry. If it is really wet you can flood out your crop, especially small seeded crops like carrot. Another thing John likes about the furrows is that when you cultivate you are throwing a little bit of soil into this furrow, burying weeds that might be germinating in the row between the plants.

Recently prepared seedbed. Note the nice furrows made by the Williams tools system as markers and the small soil clods. The Planet Junior can plant into this uneven seedbed.

Transplanting

Do I transplant by hand or with a transplanter?
"Speed is no different with the transplanter," John says. The main difference is the water with the water wheel transplanter that they use (from Nolts). Because the transplants are planted into water released by the teeth of the large marking wheel, transplants don't have to be watered right away. The other advantage is physical exertion. It is

"easier on the body" to plant while seated on the back of the transplanter.

Whether they transplant by hand or with the transplanter is weather dependant. If it is going to rain they will bed up the areas they plan to transplant and then they can still go in by hand.


Photo: seedsofchange.com

Tricks for hand transplanting. Having the right tool can make hand transplanting easier. They use a trowel when transplanting into plastic because it pierces the plastic nicely. But for transplanting into bare ground, John recommends a Japanese planting hoe. Available from Seeds of Change, the swinging action of this small hoe takes the impact off your wrist.

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Creating a Weed Management Plan for Your Organic Farm

Successful weed management can make or break a new organic farm. These steps will help you get the upper hand on weeds.

Step 1: Know your weeds

Why should it matter which weeds you have in your field? You are just going to cultivate them anyway, right? Don't be fooled.

Empower yourself with knowledge. Successful organic farming is knowledge intensive. Knowing a little about weeds their biology and ecology can go a long way toward reducing their impact. Making a list of the weed species that you have is a great first step and can be easy with the help of a good guidebook or weed identification website (e.g., *Weeds of the Northeast* by Uva, Neal and DiTomaso).

Know your weeds to avoid problem fields. Before you rent or buy a new farm, make sure you know if you have a severe infestation of especially problematic weeds. Farmers usually name perennials like Canada thistle, johnsongrass and quackgrass as their top problem weeds. Perennials store energy in rhizomes, corms and roots. For example, johnsongrass emerges from rhizomes (underground storage structures that look like thick creamy-colored roots) in mid May, and can grow to seven feet tall by July. Giant ragweed is an annual weed that can be just as much of a nuisance. Take the time to identify weeds on your farm so that you can avoid an uphill battle when you're starting off.

Know which weeds you have to avoid making problem weeds worse. If you have perennial weeds like quackgrass, hoeing or disking may merely cut the rhizome into many small pieces. Since each individual rhizome segment can grow into another new plant, this makes your problem worse.

Quackgrass is a weed you should learn to recognize. If you have it on your farm you will want to know where it is, contain it and work hard to manage it. Quackgrass produces rhizomes, underground shoots that look like roots (as well as seeds). These rhizomes spread quickly, up to ten feet per year from the parent plant. Even when chopped into small pieces, each piece can grow into its own plant. Weeds like quackgrass can quickly overtake your organic garden or field. However, once

Know your enemy. Young johnsongrass plants look a bit like corn, but don't be fooled.

Photo M. Schonbeck.

Johnsongrass, in particular, can make it practically impossible to farm organically until you get it under control. Young plants look a bit like corn, but don't be fooled. Because this plant has rhizomes, it will come back when you hoe it until you starve all the energy out of the rhizomes. A new Pennsylvania organic farmer had to abandon her vegetable field to johnson-grass eight feet tall. You have enough to deal with as a new farmer, don't give yourself an undue headache if you can avoid it.

you know how it grows, it is possible to control it. If the infestation is not severe, regular hoeing or cultivation of the quackgrass can eliminate the plant. Try to remove the shoots before the fourth leaf develops, this is the point at which carbohydrates are transported back to replenish rhizome energy reserves. For severe infestations, use a cultivated fallow in the summer. Use a spring or spike-tooth harrow during the hot, dry part of summer to bring rhizomes to the surface where the sun can dry and kill the rhizomes [1]. If a harrow is not available, repeated disking at intervals that allow small pieces of rhizome to re-grow and exhaust the rhizome, but not put any more energy back into the rhizome, will starve the rhizomes.

Know your enemy. A single quackgrass rhizome node can produce 14 rhizomes with a total length of 458 feet in one year [1].

Quackgrass has distinctive clasping auricles which grasp the stem at the base of each leaf .
Photo D. Swan, Washington State University

Know where your weeds are on your farm. Some weeds are good at growing everywhere, but most weeds occur in patches. By knowing where these patches are on your farm, you can increase management intensity and reduce their density to a tolerable level.

Answer the following questions about weeds on your farm:

- What are the main weeds in each crop on the farm?
- When and where do these weeds cause problems: pre-plant, pre-emergence, early or later in crop development, between-row, within-row?
- Map your weeds. Note on your field map where your problem weeds occur and how this changes year to year.

Step 2: Design your rotation to optimize weed suppression

Rotate, rotate, rotate. Growing the same crop year after year will favor the same weeds. Rotate crops to prevent weeds from becoming adapted to your farm.

Protect poor competitor crops by planting them after 'cleaning' crops. Slow growing crops like alliums and carrots should follow a crop that reduces weed populations. This might be a short-season crop like lettuce that is harvested before weeds have a chance to go to seed or a competitive cover crop that smothers out weeds.

Rotate between crops that have different characteristics. Diversity is key to keeping your crops from being over-run by weeds. Many weed species are adapted to specific environments, so rotating between different groups of crops can be very effective at reducing weed problems.

Follow weedy crops with crops that are easy to keep clean. Some crops are more difficult to keep weed-free than others. For example, unmulched winter squash always has a few weeds by the end of the season. The trailing vines make it difficult, if

"Rotation of crops...is the most effective means yet devised for keeping land free of weeds. No other method of weed control, mechanical, chemical or biological, is so economical or so easily practiced as a well-arranged sequence of tillage and cropping."
— C.E. Leighty.
1938 Yearbook of Agriculture

not impossible, to cultivate or even hoe once they are established. Follow weedy crops with a rapid succession of short season crops like spinach or lettuce that will be harvested before weeds can set seed. Crops, like potatoes, that are easy to cultivate, are another good choice after weedy crops [2].

In 2005 researchers at Cornell University had a sweet corn crop with ineffective weed control. Four- and five-foot tall pigweed shed thousands of seeds. Researchers measured 12,000 seeds per square foot. They knew if they followed sweet corn with early salad mix or another early crop without a lot of cultivation they would be in trouble. Instead, in 2006 they planted fall cabbage. The cabbage was easy to cultivate. Cultivation and just one pass with a hand hoe kept pigweed from going to seed. When they measured the seed bank again, there were only 3,000 seeds per square foot, one-quarter of what they had the year before [2].

For weed-infested fields, consider including a tilled fallow period in the rotation to flush out and destroy annual weeds. In a tilled fallow, you are setting aside a few weeks or months to repeatedly stimulate weed seeds to germinate and then killing them with cultivation. This can reduce the weed seed bank in your soil.

First you till the soil. Most seeds need light to germinate. Light is a cue that tells the seed there is not a lot of competition. Tillage gives buried seeds the flash of light needed to stimulate germination and you generally get a flush of weeds as a result. Tillage also releases a burst of nitrogen which can also prompt germination [2].

When the weeds are still tiny, follow up the flush of weeds with shallow cultivation (or flaming). In especially problematic areas you may need to repeat this practice a few times.

This practice works best when there is adequate rainfall to facilitate the germination of weed seeds, so keep an eye on the weather and consider irrigation, if possible.

Keep in mind that this strategy does not allow cash cropping during the fallow period. But this is part of the "cropping system."

Use a stale seedbed to protect slow-to-germinate crops. First form your seedbed. After the first flush of weeds germinates, kill them with flame weeding. Your crop will then germinate into a relatively clean seedbed. The trick is to avoid disturbing the soil surface which might bring up new weeds.

Rotation with bare fallow: field cultivators with rows of tines or sweeps can be used to dig up and lift quackgrass rhizomes to the soil surface where they will dry out and die in hot, dry weather.

Photo V. Grubinger, Vermont Extension.

Minimize niches for weeds in the field. Terry Kromer from Clear Springs Farm in Easton, Pennsylvania, got "tired of killing weeds all the time" and started planting annual ryegrass between beds with a drop seeder. She uses a flat plastic layer that allows her to mow right up to the bed.

Photo S.T. DuPont, Penn State University.

Design your rotation to optimize weed suppression -- Nordell's Beech Grove Farm Example

Anne and Eric Nordell use a fallow year before onions to reduce weed pressure and spread weed management throughout the season. From "Weed Free Onions" [3].

Fallow year

Fall: First cover crop -- rye after previous cash crop or spring oats (mowed before head) prevents mustards and others from going to seed.
June or July: Plow in first cover.
July-August: Harrowing every 2-3 weeks brings roots and rhizomes of perennials to the surface to dry in the sun and prevent annual weeds from establishing.
August: Seed second cover crop, generally Canadian field peas ***and/or oats*** that will winter kill. ***A winter-killed cover crop allows you to get in an early spring cash crop the following year.***

For example, carrots are one of the hardest crops to protect from weeds. Most weeds germinate in 3-5 days. Carrots germinate in 7-21. If you seed your carrots and flame a day or two before they germinate, there should be many fewer weeds for carrots to compete with.

The advantage to flaming versus more tillage is that you do not disturb the soil at all. This way you do not bring up new weeds seeds to the surface where they will germinate. Instead the crop germinates into a "clean" bed and has a head start on the weeds.

Step 3: Group crops with similar management

In order to simplify your weed management practices, group crops that will be managed similarly. This will save time adjusting equipment and allow you to block similar crops close to each other in the field. For rotation management, farmers usually group crops together that are in the same family (see Start Farming Fact "Planning a Crop Rotation from the Start"). For weed management it also helps to group crops within families or group together families that have similar row spacing or other management commonalities. For example, tomatoes, peppers and eggplants may all be mulched with black plastic on your farm. Grouping them together means you can lay all the plastic at once. Root crops such as carrots, beets and turnips are not all in the same family, but they are often grown on the same spacing. If you are using mechanical cultivation, you can set your cultivator up to run between three rows and do

Weed Management During Transition

Organic vegetables are often established on old hay fields or pastures to shorten time to certification. These fields may have severe infestations of perennial weeds and dense seedbanks of annuals.

- Avoid planting vegetables the first year.
- Start with a cover crop.
- Till in the cover crop before perennials get large or annuals go to seed.
- Repeat at 4-6 week intervals all summer.
- Tilled fallow will deplete the seed bank and exhaust perennial roots.
- In early August plant a cover crop, such as sudax or buckwheat that will winter kill.
- This cover will compete with weeds in the fall and leave the field ready for planting in the spring.
- If weeds are still likely, start with short season crops like lettuce that will be out before weeds go to seed.

from Charles Mohler "The Grower's Handbook to Ecological Weed Management" pg 57.

that entire section of your field with the least time adjusting equipment.

Common groups for weed management might be:
Solanaceous crops - tomatoes, peppers, eggplants
Cucurbits - summer squash, cucumbers, winter squash
Greens - spinach, lettuce, chard, kale
Roots - carrots, beets, turnips
Legumes - peas, beans
Brassicas - cabbage, broccoli, cauliflower
**Note: Because these groups include multiple families, you may need to avoid multiple groups the next year to avoid disease problems.

Step 4: Have the right tool for your system

Ever try to use a wrench as a hammer? Having the right tool for the job can make a big difference in how successful you are with weed management. Don't expect your equipment to do more than its share. It is also important to make sure your system and your tools work together. If your cultivator is only four feet wide, a five foot wide bed may be difficult to handle.

Have the Right Tool for Your System - Market Garden Example

Available tools
5 inch stirrup hoe
3-1/4 inch stirrup hoe

Available resources
straw from farm
paper mulch from year before

Tools to acquire
Wheel hoe with 8 inch and 5 inch blade to increase efficiency and provide control between beds.

Bed and row spacing
Beds are on 5 foot (60 inch) centers with 1 foot pathway and 4 foot beds. Rows are spaced 60 inches (1 row), 24 inches (2 row), 10 inches (4 row) or 4 inches (9 row).

System/Tool for each crop group

Crop group	System/between row spacing	Tool
Solanaceous crops	black plastic mulch, 60" spacing	
Cucurbits	straw mulch, 24" spacing	
Greens	4 row, 10" spacing	8" wheel hoe, 5" stirrup hoe
Baby greens	9 row, 4" spacing	3-1/4" stirrup hoe
Roots	4 row, 10" spacing	8" wheel hoe, 5" stirrup hoe
Legumes	2 row, 24" spacing	8" wheel hoe
Brassicas	2 row, 24" spacing	8" wheel hoe

Have the Right Tool for Your System - The Seed Farm Agricultural Incubator, Lehigh County Example

Available tools
Wheel hoe, hand hoes (hula, collinear), Williams Tool System (with hilling discs and side knives), I&J 2 row low residue cultivator, compact raised bed mulch layer, 3 row budding weeder.

Available resources
Straw, compost

Tools to acquire
None (Note: This is a demonstration farm and may have more than adequate equipment.)

Bed and row spacing
6' centers (5' beds with 1' pathways due to wheel base of tractor). Rows are spaced 72" (1 row), 28" (2 row) or 14" (3 row).

System/Tool for each crop group

Crop group	System/between row spacing	Tool
Solanaceous crops	Black plastic/1 row	Raised bed mulch layer
Cucurbits	straw	Side knife cultivation before mulching
Greens	3 row, 14" spacing between rows	Basket weeder/hand hoes
Roots	3 row, 14" spacing between rows	Williams Tool System tine weeder
Legumes	3 row, 14" spacing between rows	Williams Tool System tine weeder + side knives
Brassicas	2 row, 28" spacing between rows	I&J or Williams Tool System side knives or wheel hoe

When designing your system think about:

- Which crop groups will have mechanical versus mulch-type weed control?
- What tools do you already have?
- What resources are available or less expensive in your area?
- What tools do you want to acquire? Think about what might be affordable and appropriate to your scale.
- What bed and row spacing will you use to optimize the efficiency of your tools and accommodate optimal row spacing for your crop [5-6]?

One of the most overlooked aspects of mechanical weed management is adjusting the action of the implement. Just because the settings on your cultivator worked well last year doesn’t mean they will work again in a new field under different conditions. Before going into a crop field, it’s important to adjust cultivators and test their action to make sure they are doing what you want them to do. It’s also important to check what they are doing to the crop plants once you start cultivating.

Step 5: Make cultural practices work for you

Too often organic farmers focus on tillage and cultivation to control weeds. True, as a new organic farmer, you will need to choose an appropriate cultivation scheme for your farm. But like many things, an ounce of prevention is worth a pound of cure. In addition to preventing weed problems, there are a number of little things that you can do to give your crops an advantage over weeds. These little things are called cultural practices, and although they may not be very effective alone, when combined, they can be very powerful. This approach of combining cultural weed management practices is known as the "many little hammers" approach. Together many tactics that each reduce the number or size of weeds by 5-10% can provide important and often cheap control [4].

Prevent the arrival of new weed species. Weed seeds may hitch a ride to your farm in cover crop or forage seed, straw, hay, compost or manure. For example, at the Seed Farm in Vera Cruz, Pennsylvania, cocklebur was introduced to the farm with municipal compost. Knowing the source of your inputs and discussing weed seed contamination with the farmer or company you get them from is a good practice. One way to reduce introducing foreign weed seed is to clean your seed (especially cover crop seed) and use farm generated inputs such as mulch, compost and manure. Mowing adjacent areas and field edges is also a good practice to prevent weed seeds from blowing into your fields.

Prevent weed reproduction. Weeds are notorious for producing copious amounts of seeds. One common purslane plant can produce two million seeds [7]. One way to keep weeds from going to seed is cleaning up the field (mowing or tilling) quickly after the crop is harvested. Delaying cleanup by a month can increase seed production by one hundred fold [8]. Cutting off or hand pulling a few weeds that are about to go to seed before the crop is harvested can also help control the weed seed bank. See figure pg. 8.

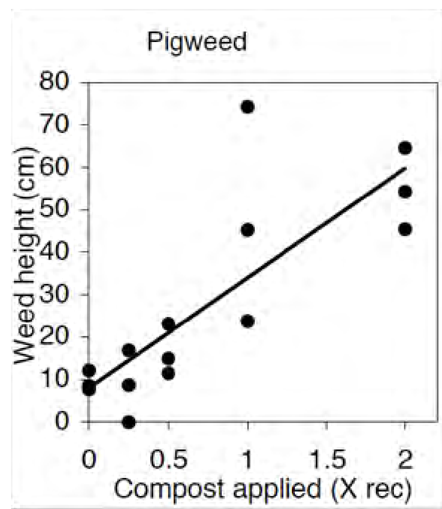
Match soil fertility with crop demand. Weeds can be better at taking up nutrients than crops. More nutrients equals bigger weeds [4]. For example, in a study at the Martens' Farm in New York pigweed grew about twice as fast when compost was applied and supplied nutrients at double the recommended rate [9]. Ideally, highly available soluble fertilizers should be avoided when possible. Instead, compost and cover crops should be used to provide nutrients that are released slowly over time. This is because nitrogen in organic matter needs to be mineralized, a process that is dependent on soil microorganisms. Soil organic matter acts as a resource sponge

Galinsoga covering this bed likely arrived with compost added last year.

Photo. S.T. DuPont, Penn State University

"A healthy crop is my most important weed management tool."

Farmer Jim Monroe [10].



The change in pigweed growth in corn at the Martens' Farm in August 2007 when the corn had filled in between the rows.

From T. Bjorkman [9].

and can mediate competition between crop and weed plants. If you do have to apply highly available nutrients like blood meal or composted chicken manure, try to apply them close to the crop so that the crop and not the weeds receive the nutrients, and work them into the soil [4]. Make sure they are not applied too closely or the crop might be injured.

Let the crop suppress the weeds. Vigorous crops can often suppress weeds, especially once they have formed a canopy that shades the soil surface. Using transplants creates a size hierarchy between the crop and emerging weeds, giving crops a major advantage. Another important way to get a weed suppressing canopy quickly is to pay attention to planting depth and uniform spacing. Planter skips and uneven seeding depth can result in gaps in the crop canopy where weeds will establish. Try to keep your planter in good repair and well adjusted so you get uniform, quick emergence. With hand push seeders this can be especially difficult, see seeder reviews in Start Farming Fact “Selecting the Right Seeding and Transplanting Techniques” for ideas. An even soil surface with few clods will also help increase uniform stands.

Step 6: Create a weed control calendar and get your timing right

If you have ever tried to chop down a garden of weeds waist high, you learned the first lesson of timing. Get ’em while they’re small. But when there are transplants to set out, crops to harvest and a farmers’ market to go to, it is easy to miss the critical windows of opportunity. Those windows are when the crop is first planted, when the flushes of weed seedlings are just emerging and during the crops minimum weed free period [6].

In business, location is everything, but in weed management, timing trumps all. Once you have the basics down, refine your management plan by improving your timing of management practices.

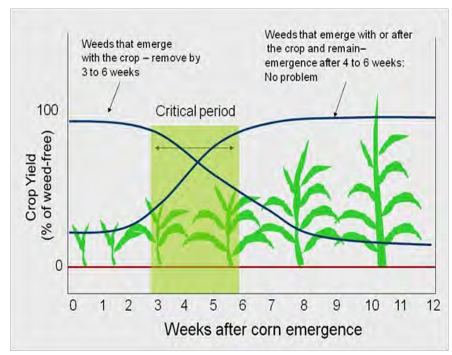
White thread stage. It is critical to target weeds while they are susceptible to control practices. Weeds are easiest to kill when they are just emerging, before you can see their leaves. This period is called the white thread stage because weeds in this stage look like little white strings in the soil. Experienced organic farmers will tell you that if you can see the weeds from the tractor seat, you missed your window of opportunity.

To help ensure you don’t miss those windows, it is helpful to create a weed control calendar based on your planting and transplanting dates. For example, at Liberty Gardens in Coopersburg, Pennsylvania, they schedule cultivation one or two weeks after setting out transplants. By that point most crops have formed a canopy and weed growth is minimal (in fields

Years required for a reduction in the weed seedbank

	50%	99%
--Common Lamb-squarter (*Chenopodium album*)	12	78
--Field pennycress (*Thlaspi arvense*)	6	38
--Yellow foxtail (*Setaria glauca*)	5	30
--Prostrate knot-weed (*Polygonum aviculare*)	4	30
--Giant foxtail (*Setaria faberi*)	> 1	5

Adapted from references [5, 6].



If you can manage weeds in the first few weeks, the canopy will close and the few weeds that escape are not likely to reduce your yield.

From B. Curran, Penn State University.

where they have reduced the weed seed bank).

If you have many intensive vegetable plantings, it may help you to create a weed control calendar. Many producers plan their seeding and transplanting dates using spreadsheets. Add another column to the spreadsheet that calculates "projected" weed
control dates. Of course, Mother Nature and other factors will often shift your dates, but the calendar will serve as a reminder and help you hit the windows of opportunity.

Additional Reading and Resources

"Cultivation Equipment for Weed Control: Pros, Cons and Sources." by Vernon Grubinger, Vermont Cooperative Extension, 2001.
"Design the Cropping System and Select Tools for Effective Weed Control" from www.extension.org by Mark Shonebeck, Virginia Association for Biological Farming.
"Sustainable Vegetable Production from Start Up to Market" by Vernon Grubinger, 1999, Ithaca, New York: National Resource Agricultural Engineering Service, Cooperative Extension.
"Preventative Practices in Organic Weed Management" from www.extension.org by Dr. Charles Mohler, Cornell University, and Mark Shonebeck, Virginia Association for Biological Farming.
USDA Plants Database: http://plants.usda.gov/java/
"Weeds of the Northeast" by Richard H. Uva, Joseph C. Neal and Joseph M. DiTomaso. 1997. Cornell University Press.

References

1. Westwood, H., K. Cox, and E. Gallandt, *Quackgrass: Management on Organic Farms*, University of Maine Sustainable Agriculture Program.
2. Mohler, C.L. *The Role of Crop Rotation in Weed Management* in Mid Atlantic Fruit and Vegetable Conference. 2011. Hershey, PA.
3. Nordell, A. and E. Nordell, *Weed-Free Onions.* Weed the Soil Not the Crop, 2007.
4. Mohler, C.L. and A. DiTommaso, *The Grower's Handbook of Ecological Weed Management*. to be published: Department of Crop and Soil Sciences, Cornell University.
5. Schonbeck, M. *Design the Cropping System and Select Tools for Effective Weed Control*. eXtension; Virginia Association for Biological Farming www.extension.org 2010.
6. Schonbeck, M., *Knock Out Weeds at Critical Times.* eXtension.org, 2010.
7. Norris, R.F., *Weed fecundity: Current status and future needs.* Crop Protection, 2007. 26: p. 182-188.
8. Brainard, D., C.L. Mohler, and M. Schonbeck, *Manipulating Weed Seed Banks to Promote their Decline.* eXtension.org, 2010.
9. Bjorkman, T., ed. *Organic Fertility Recommendations*. In: Organic University; Advanced Row Crop Management. Midwest Organic Sustainable Education Service. 2008. 65-80.
10. Davis, A., K. , et al., *Integrated Weed Management "One Year's Seeding."* Extension Bulletin, E-2931, East Lansing, MI. Michigan State University, 2005.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension; Matthew Ryan, Penn State Weed Science. Reviewed by Bill Curran, Penn State Department of Weed Science and Lee Rinehart, Pennsylvania Certified Organic. Last updated November, 2011.

Quiet Creek CSA, Kutztown PA Weed Management

John and Aimee Good run Quiet Creek Farm, a certified organic CSA raising vegetables, berries, flowers, and herbs for 200 members. The farm is located on 8 acres of land leased from the Rodale Institute in Kuztown, PA.

Problem Weeds

At Quiet Creek CSA, like most organic vegetable farms in our area, galinsoga is the number one weed problem. Low growing and quick to seed, it is hard to keep ahead of. Pigweed, lambsquarter, foxtail and ragweed are also important weeds at their farm. These summer annuals are adapted to the organic grains grown on the farm prior to Quiet Creek's start-up. These large weeds can overwhelm crops quickly and so John and Aimee have an aggressive weed management strategy.

Preventing Weed Problems – Crop Rotation

John and Aimee use crop rotation to protect vulnerable crops and reduce overall weed pressure at the farm. One strategy they use is to follow easy to keep clean crops with hard to cultivate crops. For example, they might follow crops in black plastic with root crops.

Belly mounted sweeps on John's Kubota tractor. These sweeps can get very close to crops killing weeds between rows and throwing soil in row burrowing in row weeds.

Quiet Creek uses fallow periods in the rotation to reduce weed pressure. To do this they only use each bed only once per season. This gives them time to use a 'green fallow.' The green fallow is a cover crop, usually buckwheat, that is grown and then tilled in. Buckwheat works well. Seeded at 50 lbs per acre it grows fast, shading out weeds. In three to four weeks it is ready to be tilled in, beating weeds to seed. Tilling in the buckwheat kills weeds that have germinated before they have a chance to go to seed, reducing the weed seed in the soil. Then that area can be planted to a fall over wintering cover crop.

Crop Groups to Keep Management Simple

Crops with similar management are kept together on the farm. This makes it simpler to cultivate, irrigate and manage crops. They have roughly an acre of each of the following: spring greens, spring/ fall roots, plasticulture solanaceae/ cucurbit crops, late cucurbits on bare ground, fall greens/ brassicas, and potatoes.

The Set-up – The Right Tools for the System

The general system at Quiet Creek is beds on five foot centers (43 inch bed tops with 17" between beds). Planting is in one, two or three rows. They don't use four or five rows per bed primarily because it is hard to cultivate. Three rows per bed spaces crops 15 inches center to center. Two rows per bed spaces crops 30 inches apart.

Williams tool system behind Kubota with belly mounted sweeps. Tines can all be down to kill in row as well as between row weeds or lifted over the row. Photo by Daniel Paashaus.

Row marking knives are the three straight bars going vertically into the ground. They mark the rows, keeping them straight and parallel. This way even if they are hand planted they can be mechanically cultivated.

Roots & Greens are planted three rows per bed. Weed management starts with a stale seed bed. They use a Williams Tools System which has many spring tines. These tines are set to just barely cultivate the bed surface, killing tiny weeds without disturbing the soil below which would bring up more weeds. At the same time they mark rows using three row marking knives that are attached to the tool bar right over where they plan to plant. One to two weeks after seeding or transplanting into the small furrow made by the row markers they cultivate. They use a Kubota tractor that has belly mounted cultivating sweeps. The sweeps cultivate between the rows of the crop. Attached to the rear of the tractor is the Williams Tools System with its full set of spring tines down to cultivate in as well as between rows. But they still have to come back and hoe and hand weed. "This is the number one expenditure of labor on the farm," John says.

Solanaceous Crops are generally planted into black plastic. They use a plastic layer to lay a four foot wide sheet of plastic over the beds. This warms the soil and controls weeds in row. But you still have to control weeds between the plastic and this is "one of the hardest spaces to cultivate on the farm," John says. They control weeds in this hard to manage area using the outer knives of the Williams Tool System with two track sweeps to clean up under the tractor tires. These knives cut weeds just below the surface, reaching just under the plastic. It will actually lift the plastic up a bit and then the tractor tires pack it back down. This can be tricky and soil moisture has to be just right.

Cucurbits. Early cucurbits are planted into black plastic and managed like the solanaceae crops. The later plantings are on bare ground. They also use the Kubota with belly mounted cultivating sweeps and the Williams Tool System for these crops. The first cultivation is about one week after planting. The sweeps on the Kubota get nice and close to the rows and throw some soil into the row, burying in row weeds. In this case all the spring-tines are up on the Williams. They use special thirteen inch pumpkin knives mounted on the William's tool bar. These knives reach right up to the root ball of the plant under vining crops like cucumbers. Track sweeps clean up the area behind the tractor tires.

John Good shows field day participants track sweeps. These sweeps are behind tractor tires.

Advice

John has two pieces of advice for new farmers.

"Go fast and get close." As the old farmer saying goes, "If you are not every once in a while killing a crop plant you are not going fast enough."

"Weed control is the biggest issue on organic farms. So have a system in place before you ever put a seed in the ground. This will help you more than anything else."

For more details this farm profile is available as a video clip. Visit extension.psu.edu/start-farming to hear from John and see their weed control strategy.

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, March 2012.

Gottschell Farm, Coopersburg PA — Weed Management

Steve and Nicole Shelly farm an acre of vegetables, herbs and cut flowers using organic practices. They sell at local farmers markets and through their CSA.

Problem Weeds

Galinsoga.

Nicole says galinsoga is a problem weed on their farm. Galinsoga goes to seed very quickly, in just five weeks. Because it goes to seed so quickly, before most crops are harvested (even lettuce); it spreads fast. It seems to like fertile vegetable soil. Nicole and Steve work hard to try to keep it from going to seed. In addition to hoeing and hand pulling they may weed-wack fallow areas that they don't want to till again until later.

It is good to know a little about galinsoga to keep it from taking over your field. Since it goes to seed so quickly you need to keep an eye on it and give it regular attention. The seed generally germinates very close to the surface. If you have an area infested with galinsoga and time to fallow you can let a lot of it germinate in the spring. Wait until it just starts to flower then you can till shallowly and kill most of the seeds before an early summer crop. They also say that rotating to sod for 3-4 years can help because the seeds don't live for very long.

Pea shoots for salad mix. Grown twelve rows per bed, pea shoots are competitive and fast. In just three weeks they are out before any weeds can go to seed.

Design the System – Protect Poor Competitors by Planting them after Cleaning Crops

At Gottschell Farm they grow a lot of pea shoots for salad mix. They have found that when they plant the pea shoots densely: 12 rows on a 4 foot bed top, they seem to compete well with weeds. The pea shoots are also short season. After just three weeks Nicole will be tilling again to prepare for the next crop. That will kill any small weeds that might be breaking through the dense pea canopy. After 'cleaning' pea shoots they might grow leaf lettuce. It will then be relatively weed free and easy to harvest.

They also use potatoes to clean up beds because they hill them a lot, keeping them very weed free. Cover crops before onions is another nice combination.

Crop Groups to Keep Management Simple

Steve and Nicole group their crops to help with rotations, manage fertility and keep crops with similar irrigation together. It also helps with weed management. All their mulched crops are together, and crops with similar spacing are grouped together. Their crop groups are solanaceae, lettuce/greens, cucurbits, potatoes, carrots, pea shoots, and beet/chard.

The Right Tool for the System

Steve and Nicole used to farm in Philadelphia where they had a lot of volunteers. There the main weed strategy was hand weeding. They have kept many of the intensive practices they refined as urban farmers on their new farm. For example carrots are sown 12 rows per bed which pretty much must be hand weeded. But now that they don't have as much labor at their disposal they try to keep most of their spacing wide enough to use a scuffle hoe.

Some crops like carrots are hand weeded.

Crop group	System/ between row spacing	Tools
Solanaceous	5' 6" on center Mowed down rye	High field mower, weed wacker
Cucurbits	5' 6" on center Mowed rye or plastic	High field mower, weed wacker
Lettuce/ Greens	4' bed, 6" between rows (6 rows)	5" scuffle hoe
Potatoes	Narrower spacing to fit hiller	BCS hiller
Carrots	12 rows per bed	Hand weeding
Pea shoots	12-20 rows per bed	No weeding
Beets/ Chard	4 rows per bed	5" scuffle hoe

Tomato beds above are direct planted into mowed down rye. Sometimes they add additional rye mulch on top.

Steve and Nicole also use a good amount of mulch on the farm. They like rye mulch because they can grow it themselves, limiting off farm inputs and plastic. Rye cover crops are planted in the fall. In the spring they let them get tall. It is important to wait until they are forming seed (the

Gottschell Farm, Coopersburg PA Weed Management

seed should be starting to be doughy, not all green) before they mow it down. They use a weed wacker and a high field mower to chop down the rye. This leaves a nice mulch that they have grown in place. They know it is weed seed free and clean because they grew it and they don't have to move it. Then they can transplant tomatoes and cucurbits right into the mulch. If the rye was not thick enough they will supplement with additional rye straw.

Cultural Controls to Keep the Weeds at Bay

Healthy crops compete well with weeds. High quality soil and healthy transplants make vigorous plants that grow quickly and shade weeds. Steve and Nicole are also working to match soil nutrients with crop needs. Now that they have built up their organic matter they are using cover crops, small amounts of organic fertilizer for nitrogen and limited compost applications to maintain soil fertility instead of adding compost every year.

Timing

With so many crops clammering for attention it can be easy to skip a cultivation. But Steve and Nicole know how important it is to keep on top of weed management. Usually they hoe a crop the first time about a week after planting when weeds are still tiny, sometimes barely visible. The second cultivation is about two weeks after the crop is planted.

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Branch Creek Farm, Perkasie PA — Weed Management

Mark and Judy Dornstreich have been farming for over 30 years in beautiful Bucks County, PA. They produce baby greens, specialty vegetables and edible flowers year-round in 3 greenhouses. Come summer, they shift their attention out to the field where they grow unique vegetable varieties on about 5 acres. They provide Philadelphia and New York City restaurants with only the highest quality, mouth-watering produce.

Greenhouses

Mark makes his own compost for out in the fields but the prevalence of weed seeds within that compost is potentially high. So he buys in McEnroe Organic Compost for greenhouse beds in need of additional nutrients. Buying in a clean compost mix means the weeds stay out of the greenhouses.

Buying seed from reliable sources also cuts back on weeds. It's important to read the seed pack before seeding beds in your greenhouses with them. Sometimes they contain "% noxious weed seed". You want to avoid using seed like that in a closed environment.

The term "weed" means any undesired plant. A common problem in the greenhouse is that beds are not always cleaned as thoroughly as they should be. Not all the seeds planted in a bed germinate at the same time. Sometimes when you are harvesting a crop, seeds that haven't germinated yet are still in the bed. If those seeds fall deep into the bed when you're cleaning it, most likely they will germinate with the new crop you intend to plant. For example, you could have a nice stand of arugula coming up with patches of radish all throughout it. This makes the arugula hard to harvest and takes more time than it should.

In the Field

"Organic growers are too hung up on weeds" says Mark. "I don't mean you should let them take over but I don't think you need to spend all your time cultivating. From what I can see of the weeds growing out of the pavement, they don't require a whole lot of nutrients to survive. I just make sure to put down enough compost for everyone, that way there's no competition." The way he sees it, weeds are just plants. When you make a perfect bed for seeding with plenty of nutrition, you're just making a better environment for the weeds, also.

The biggest threat weeds pose is shading out the crop. To prevent that from happening, Mark advises "cultivat[ing] them before you even see them…and don't EVER let them come up before the crop. If that happens, you might as well just get out the disk".

Just about all the field crops get planted on black plastic mulch. The mulch gets layed a few days before planting, which possibly raises the temperature under the plastic high enough to kill weed seeds. Also, it prevents weeds from coming up around the plants. The "trouble spot" is right along the edge of the black plastic mulch. That is where the majority of the weeds will show up. After planting, Mark will mulch right up along the sides of the plastic. This suppresses the weeds along the edges, resulting in weed free beds!

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Aston Ward, Penn State Extension. Photos taken by Aston Ward, courtesy of Branch Creek Farm. Last updated May 2011.

Liberty Gardens, Coopersburg PA Weed Management

Jeff Frank and Kristin Illick run Liberty Gardens in Coopersburg, PA. They specialize in salad greens and heirloom tomatoes and market primarily to restaurants in New York and the Lehigh Valley. Many of their greens are grown in benches in high tunnels.

Design the System – Rotations and Cover Crops Reduce the Niche for Weeds

At Liberty Gardens they incorporate a lot of cover crops into the rotation. Not only are the cover crops great for the soil but they compete with the weeds. Jeff and Kristin also grow a lot of short season crops in rapid succession. Many of their beds grow three crops in a single season. This quick turnover "does not allow weeds to get a hold."

Jeff describes their cover crop system of oats and peas to the Introduction to Organic Vegetable Production class.

The System

Jeff and Kristin grow a lot of their greens in benches in the greenhouse. For outside production they have beds set up on five foot centers (four foot beds with one foot pathways). The tractor tire makes the paths and designates the width of the beds. In the past they have used a cub with basket weeders belly mounted on the tractor to control weeds. This kept them to three rows or less per bed because of the way the cultivator is set up. A few years ago they went away from tractor based cultivation which allowed them to increase the number of rows per bed, but also increased their labor demands. They often use up to five or six rows per bed but they always make sure there is still enough space to get in with some sort

Crop group	System/ between row spacing	tool
Solanaceous	Leaf mulch or landscape fabric 5' center	
Cucurbits	no mulch 5' center	
Lettuce	5' bed – 6 rows	3 ¼" scuffle hoe
Greens (other)	5' bed – 5 rows	Push hoe 8", scuffle 5"
High Tunnel	3' beds	Scuffle hoe

Jeff, Emma and Jen planting lettuce into straight even rows marked with a ganged Earthway seeder.

of a hoe to cultivate.

Even Row Spacing Makes it Easier to Go Back and Hoe Later.

Jeff says it is really important to keep the rows straight and evenly spaced so that he can come back in and hoe. He uses an old Earthway seeder that has three seeders ganged together. One pass with the seeder (with no seed) leaves three evenly spaced marks one foot apart. With a double pass the marks are six inches apart for lettuce. Then they can still get in with the five inch or three and a quarter inch scuffle hoe.

Jeff marking rows with a three Earthway seeders that have been ganged together.

Straight and more important parallel rows of lettuce are easier to hoe. The even spacing leaves enough space to fit a hoe without so much extra space to require two passes.

Jeff uses leaf mulch because "it is there." Liberty Gardens is just down the road from the municipal leaf disposal area they drop it off at the farm for free. It provides a nice mulch, suppressing weeds, retaining moisture and providing organic matter. Jeff and Kristin have experimented with all different types of mulch – plastic, straw, and landscape fabric. This year Jeff is trying again with landscape fabric. But he is worried about it because it is hard to sanitize and there is some potential to bring disease back into the field when reusing the material.

Leaf mulch (left) suppresses weeds and provides organic matter.

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An Organic Weed Control Toolbox

Last Updated: March 23, 2010

eOrganic author: Mark Schonbeck, Virginia Association for Biological Farming

Introduction

Organic growers utilize a wide diversity of weed control tools that can be roughly grouped into the following categories:

- Tillage tools and implements
- Cultivation tools and implements
- Mowers and other cutting tools
- Flame weeders and other thermal weed controls
- Mulches and mulch application equipment
- Herbicides allowed in organic production

Note that cover crops, diversified crop rotations, and optimum cash crop management are vital tools for *preventive* or *cultural weed management*. The tools discussed here are those used—in lieu of chemical herbicides—to deal with those weeds that emerge even in the best-managed organic vegetable fields.

Following is a brief description of the various weed control tools and how they are used to kill weeds or reduce weed competition with the crop.

Tillage Tools

Tillage done after harvest of one crop and prior to planting the next crop serves several functions, including incorporation of crop residues, cover crops, and soil amendments; removal of existing weed growth; and preparation of a seedbed for planting. Field preparation often consists of a **primary tillage** operation to break sod, loosen or invert soil, and kill existing vegetation; and a **secondary tillage** pass to form a seedbed of desired fineness. Because of the potential adverse impacts of tillage on soil quality, many farmers attempt to reduce tillage, either by making only a single pass before planting, restricting soil disturbance to only part of the field area (strip, ridge, or zone tillage), or minimizing the intensity of disturbance through shallow or noninversion tillage.

Tillage uproots weeds, severs or chops weed shoots and roots, buries weeds and weed seeds, or a combination of these, depending on the implement(s) used. Because different weed species and life stages are differently susceptible or tolerant to uprooting, chopping, and burial, the existing weed flora and weed pressure should be taken into consideration in choosing primary and secondary tillage implements, and in deciding whether, when, and how to reduce tillage.

Primary tillage tools include the moldboard (turn) plow, chisel plow, disk plows (such as heavy offset disk), rotary spaders, and rotary tillers operated near their maximum depth (6–8 inches). Secondary tillage tools include disk harrow (light disk), field cultivator, springtooth harrow, spiketooth harrow, and rotary tillers. The moldboard plow inverts the soil profile and thereby uproots and buries weeds without much chopping action. The chisel plow breaks sod with much less soil inversion and weed burial, whereas the sweep plow mainly severs weed shoots from roots but does not further fragment, uproot, or bury the weeds. Disks and rotary tillers chop weeds up and mix the fragments with soil to the tool's working depth, which effects partial burial. They are often used as secondary tillage to chop up weeds left intact by moldboard or chisel plowing. Rotary and reciprocating spaders have become popular among organic vegetable growers, as they accomplish effective tillage with less hardpan formation or damage to soil structure than other implements, often chopping and incorporating weeds and cover crops and leaving a fairly good seedbed in a single pass.

Tillage is often necessary for removing established weeds, especially perennial weeds emerging from storage roots, rhizomes, or other underground vegetative propagules. Perennial weeds, especially wandering perennials that propagate through rhizomes and other underground structures, often require careful selection of tools and methods, depending on type and depth of the underground structures by which they persist and propagate. Chisel plows and field cultivators can bring the roots and rhizomes of some perennial weeds such as quack grass or Bermuda grass to the soil surface to dry out and die, but may be less effective against other weeds like Canada thistle or field bindweed that have deep root–rhizome networks.

Whereas most tillage practices effectively remove existing weed growth, their effect on weed seeds—whether still on the plant or in the soil's weed seed bank—can vary from reducing to greatly enhancing subsequent weed emergence. Tillage can directly stimulate weed seeds to germinate by exposing the seeds to a brief flash of light or by scarifying (nicking or scratching) the seed coat. Tillage also moves seeds up or down in the soil profile, and changes soil conditions (loosening, aeration, mineralization of nitrogen, drying), which can promote either germination or dormancy. Weed seeds stimulated by tillage to germinate either emerge or die, depending on depth at which germination occurs, and whether current growing conditions are favorable. Generally, tillage hastens the decline in numbers of viable dormant weed seeds remaining in the soil. For more on the effects of tillage on weed seed populations, see **Manage the Weed Seed Bank—Minimize "Deposits" and Maximize "Withdrawals"** (/pages/18527/manage-the-weed-seed-bankminimize-deposits-and-maximize-withdrawals) , and **Manipulating Weed Seed Banks to Promote their Decline** (/pages/18528/manipulating-weed-seed-banks-to-promote-their-decline) .

At the garden scale, primary tillage is accomplished with shovel, spading fork, broadfork, or a heavy duty walk-behind rotary tiller or rotary plow operated at or near its maximum depth. Secondary tillage is done with rakes, four-prong cultivators, wheel hoes with claw attachments, or a rotary tiller run at a depth of 1–3 inches.

Cultivation Tools

Cultivation is physical soil disturbance done primarily for the purpose of controlling weeds. Most cultivation is done between the time of crop planting and the point at which the crop closes canopy (thereby severely curtailing weed growth through competition) or becomes too large for cultivation operations.

A wide range of cultivation implements have been designed and developed for full field, interrow, near-row, and within-row cultivation (Bowman, 1997). These implements are mounted on one or more toolbars and pulled along crop rows or beds to effect weed removal. Tools have been designed specifically for various crops, planting patterns (single, double, or multiple rows; level field or raised beds), stages of crop and weed development, soil conditions, and amounts of surface residue. Implements are often combined to accomplish between-row and within- or near-row cultivation in a single pass. High precision in crop row spacing and in matching crop row spacing with implement spacing on the toolbar is essential. Various guidance systems have been developed to minimize crop damage during cultivation.

Full-field implements include the rotary hoe, spiketooth harrow, spring-tine harrow, and other weeding harrows. The rotary hoe consists of two ranks of wheels, each equipped with multiple (usually 16) spoon-like projections that throw small weeds out of the soil when the implement is pulled through the field at high speeds (7–12 mph). All of these implements are effective against small, recently-germinated weeds (white-thread stage to cotyledon stage), and are used either prior to emergence of large-seeded crops (sown below the 0.5–1 inch depth at which the tool works), or at certain stages of early crop establishment when the crop is rooted firmly enough to avoid uprooting, yet not so large as to sustain too much foliar damage by the tool. This full-field or “blind” cultivation removes within-row weeds that germinate just before or with the crop, thereby giving the crop an important head start.

Interrow cultivators consisting of various shovels or sweeps mounted on toolbars singly or in gangs (depending on crop row spacing) sever or uproot weeds up to six inches tall, and are perhaps the most widely -used cultivation tools. These implements dig down about two to four inches to take out weeds, and must be mounted at sufficient distance from crop rows to minimize root pruning damage to the crop. When the crop is young, cultivators are adjusted to avoid throwing soil into crop rows, either by providing shields or by using goosefoot shovels or narrow point shovels that minimize lateral movement of soil. Shield can consist of ground-driven wheels or rotary shields, or panels or “tents” over each row, affixed to the implement. Later in crop development, the cultivator can be adjusted to throw considerable soil into the crop row to bury small within-row weeds.

The rolling cultivator consists of gangs of rotating wheels with stout curved tines, or small disks. The two gangs within each interrow can be adjusted to work more or less aggressively, and to move soil either into or away from crop rows. Two of the more aggressive between-row cultivators, effective on fairly large weeds, include the rotary tilling cultivator or multivator (also useful for strip-till seedbed preparation), and the horizontal disk cultivator. These disturb the soil more intensively, and overuse can degrade soil structure.

Near-row cultivation tools are designed to work more shallowly in the area from about two to four inches from the crop row itself. Disk hillers or spyders (ground-driven toothed wheels) can be combined with between-row tools to remove weeds closer to the crop. Brush weeders (stiff polypropylene brushes mounted on horizontal or vertical axis, effective on weeds up to five inches) and basket weeders (two gangs of wire baskets rotating at different speeds to knock out small weeds up to two inches) work the entire interrow up to within a couple inches of the crop.

Precision within-row cultivation tools include torsion weeders, spring hoes, and ground-driven spinners and finger weeders (flexible rubber “fingers” mounted on a rotating hub) work into the crop row from either side to knock out small (up to one inch) weeds without damaging established crop plants. Tips of the torsion and spring hoes vibrate just below the soil surface on either side of the row, causing the soil to “boil up” and thereby uproot small within-row weeds.

Within-row and near-row cultivation requires high precision to avoid damaging crop stands. Many farmers use specially designed cultivation tractors with belly-mounted tools so the operator can easily see and adjust tool position relative to the crop. For rear-mounted cultivators, mechanical devices such as guide wheels that run along the sides of raised beds or ridges can keep the implement on course. Electronic guidance systems sense the position of the crop row and automatically adjust the position of the implement.

Dr. Charles Mohler’s Basic Principles of Mechanical Weeding

(adapted from Mohler, 2001, p. 170–173)

1. *Row-oriented cultivators should work the same number of rows as the planter, or a simple fraction of this number*. Otherwise, small variations in spacing between adjacent planter passes can result in improper placement of tools relative to some rows, causing damage to the crop, insufficient control of between-row weeds, or both.
2. *Cultivator tools and depth of action must be appropriate for the growth stages of the weeds and crop*. Full-field implements operated after crop planting, and within-row weeders cannot dig deeply without damaging the crop. Thus, such operations must be timed to knock out weeds after they germinate and before they become well rooted. Implements that work near but not within the row also require careful attention to timing, though they can be used against slightly larger weeds without harming an established crop. Timing is less critical for most interrow cultivation tools.
3. *Create and maintain a size differential between the crop and the weeds to facilitate mechanical weed control*. Stale seedbed or preemergence cultivation delays weed emergence relative to the crop. Subsequent cultivations can increase in depth and degree of soil movement as the crop grows larger. Once they are well established, some vegetable crops like potatoes and sweet corn tolerate soil being thrown into the rows to bury small in-row weeds. However, this works well only if weeds that emerged shortly after crop planting have been killed by earlier cultivations.
4. *Cultivation becomes less effective as weed density increases*—for several reasons. First, the proportion of weeds that escape cultivation is approximately constant over a wide range of weed densities. Therefore, a high initial weed density means a higher density of escapes, which can reduce yields. With low initial weed density, escapes have little impact on robust crops, and can be pulled manually out of weed-sensitive, high value crops. Second, soil clings better to the dense mass of roots characteristic of high weed populations than to individual root systems of more isolated weeds. Many implements do not penetrate as well when roots bind the soil together. Third, a high weed density that forms a continuous cover of green plant tissue can "lubricate" the soil surface, which further interferes with the uprooting action of cultivation implements. As a result, the weeds reroot and resume growth more readily.
5. *Effective cultivation requires good tilth, careful seedbed preparation and good soil drainage*. A loose, fine tilth facilitates stripping soil from weed roots, and reduces the risk of knocking over crop plants with larger clods when soil is thrown into the row. Shallowly working tools such as tine weeders are relatively ineffective in cloddy or compacted soil, because movement of clods may facilitate emergence of weed seedlings from below the clods, and fail to kill weed seedlings within clods. Timely cultivation depends on adequate soil drainage, especially in wetter than normal seasons.
6. *Cultivation (and tillage) in the dark stimulates germination of fewer weed seeds than cultivation in daylight*. Tillage and cultivation at night, or with implements that are covered with light-excluding canopies, can reduce the density of later-emerging weeds, especially in small-seeded broadleaf species. However, since not all seeds in the seed bank require light to germinate, and some will be left near enough to the surface to receive light *after* cultivation, dark cultivation does not *eliminate* the flush of weed emergence. Consider using light- and dark cultivation to manipulate timing of weed emergence. For example, do primary tillage in the light, let weeds emerge, then prepare and plant the final seedbed in the dark. After planting, first perform shallow full-field cultivation in the dark to minimize weeds in the crop row, then do early interrow cultivations in the light to draw down the seed bank, then do a final dark interrow cultivation.
7. *Time cultivations relative to changing weather and soil conditions to optimize effectiveness*. For example, aim to cultivate early in the day during hot, dry weather, so that uprooted weeds desiccate and die before they can reroot. In particular, avoid rotary hoeing while the ground is wet, which makes this implement ineffective. Flame weeders work best when leaf surfaces are dry, so wait until dew has fully evaporated.

Market gardeners can choose from a wide range of hoes and other handheld weeding implements. The standard hoe, consisting of a fairly heavy-duty blade, is effective on a wide range of small to fairly large weeds, but the chopping motion can be tiring and tend to bring up more weed seeds to germinate. Other implements include the stirrup hoe (oscillating or hula hoe), the collinear hoe and various other lightweight, ergonomic hoes designed for very shallow cultivation of small weeds and ease of use. The short-handled Dutch hoe gets the gardener down on hands-and-knees but allows very close, precise cultivation similar to the torsion weeder and other within-row implements. The wheel hoe covers larger garden areas much more efficiently, and can be equipped with standard, stirrup, or sweep blades for different applications. The four-prong cultivator ("potato hook") can be worked shallowly to uproot small weeds, or deeply to bring larger weed roots and rhizomes to the surface.

Mowers and Cutting Tools

Farmers use rotary (bush-hog), sicklebar, or flail mowers to manage weeds in pastures, field margins, and sometimes in crop fields themselves. Whereas mowing simply removes top growth, leaving stubble of an inch to several inches in height, it can nevertheless have a significant impact on certain weeds. Some annual weeds are fairly mowing-susceptible and can be prevented from setting seed by one or two mowings, and even the growth and vegetative reproduction of perennial weeds can be restricted by timely or repeated mowing.

Three potential uses for mowing as part of integrated weed management in vegetable crops include between-row, over-the-top, and post-harvest mowing. When additional cultivation is not desired because of crop developmental stage or soil quality considerations, mowing weeds between rows of an established vegetable crop may be sufficient to prevent crop yield reductions and to reduce weed seed production. Examples might include mowing weeds just before cucurbit vegetables vine out, or between rows of snap beans, corn, or other vigorous crops a couple weeks before canopy closure. When weeds grow above the canopy of a low-growing crop like sweet potatoes or peanuts, some farmers mow just above the crop canopy to eliminate shading and seed set by the taller weeds. Finally, mowing rather than tillage after crop harvest can interrupt weed seed production without disturbing the soil or the habitat of ground beetles and other weed seed predators.

Market gardeners can use a lawn mower, weed whacker, sickle, scythe, or garden shears to cut weeds between rows, in margins, or after harvest. In addition, manual cutting tools can be used to remove weed "escapes" in larger fields to prevent weed seed production.

Flame and Other Heat-kill Tools

Many vegetable growers use propane-fueled flame weeders—backpack or tractor-mounted—to kill small weeds just prior to crop emergence (full field flaming), or between crop rows (using shields to protect crops from the heat). Organic growers often flame a stale seedbed to remove emerged weeds without additional soil disturbance, just before or just after planting the crop. Flame weeders equipped with a flame hood or shield concentrate the heat on the target weeds, and are therefore more energy efficient.

A few crops can tolerate within-row flaming at certain developmental stages, such as corn and onions that are several inches tall (growing points are protected within the plant structure), and cotton (whose stem is woody and resistant). The flame is directed toward the soil surface from either side of the row. The goal is not to "burn" the weeds, but to subject them to a *brief* exposure to intense heat, just sufficient to disrupt cell membranes and cause the weed to dehydrate and die in a few days. Flaming is most effective and energy-efficient on small weeds up to two inches tall (Diver, 2002).

Other modes of thermal weed control include the infrared heater, and hot water and steam weeders, all of which eliminate the potential fire hazards associated with flame weeders in dry conditions, especially in the presence of mulch or dry residues (Astatkie et al., 2007). The infrared weeder directs the propane flame at a ceramic or metal plate, which radiates the heat onto the weeds. It can be effective, but requires several times as much energy as direct flame. Hot water and steam units require hauling considerable volumes of water (e.g., 1,000 gal/ac) into the field, and may control weeds less effectively than flame or infrared.

Mulching

Organic mulches such as hay, straw, tree leaves, and wood shavings keep light-responsive weed seeds in the dark, physically hinder emergence of weed seedlings, and can provide shelter for ground beetles and other weed seed consumers. They also conserve soil moisture for crop production, maintain good soil tilth, prevent surface crusting, feed soil life, and sometimes provide slow-release nutrients. About three or four inches of hay or straw mulch can greatly reduce the emergence of broadleaf weed seedlings. Organic mulches are less effective against grassy weeds, and usually do not significantly hinder the emergence of perennial weeds from rootstocks, tubers, rhizomes, or bulbs.

One limitation for organic mulch is that manual application of mulch materials may be too labor-intensive for multiacre plantings. Bale choppers have been developed to mechanize application of hay or straw between wide-spaced crop rows or beds. Another approach to mulching at the farm scale has been the production of *in situ* mulch in the form of high biomass cover crops. This entails no-till cover crop management and vegetable planting, which are most feasible where existing weed pressure is light to moderate, perennial weeds are scarce, and a transplanted or large-seeded vegetable will be grown in the cover crop mulch. Rollers, roll-crimpers, flail mowers, and undercutters are used to convert the mature cover crop into *in situ* mulch at the farm scale, leaving residues either chopped fine enough (flail mowing) or oriented parallel to future crops rows to permit mechanized planting. Gardeners can cut cover crops with a scythe, sickle, or weed whacker, and plant vegetables manually with a spade, trowel, or dibble.

Living mulches consisting of low-growing cover crops between cash crop rows are most workable for perennial fruit crops, especially tree fruits and grapes. Living mulches usually compete too strongly with vegetables, resulting in yield losses.

Black plastic film mulch effectively blocks emergence of most weeds, including perennials. They also eliminate the light stimulus for weed seed germination. However, these synthetic materials do not enhance soil quality, can interfere with infiltration of rainfall, and (unless a biodegradable material is used) require pickup and disposal at the end of the season. In addition, weeds often come up through planting holes, where they can be especially hard to control. Weed barriers (landscape fabric) last several seasons and can be especially useful for getting perennial crops established. Paper mulches used alone are less effective than plastic, but a paper mulch underneath hay or other organic mulch can enhance weed control over the organic mulch alone.

Clear plastic film mulch raises soil temperature much more than black plastic. During hot summer weather, it can effect *soil solarization*, another form of thermal weed control. Solarization kills emerging weeds, some soilborne crop pathogens and insect pests, and even some weed seeds and vegetative propagules of perennial weeds. However, if conditions are too cool or cloudy to support effective solarization, the clear plastic can simply accelerate weed growth under the plastic layer by creating near-optimum temperatures.

Organic Herbicides and Bioherbicides

A limited number of products have been developed that organic growers can spray for weed control. Natural-product herbicides allowed for organic production, including acetic acid (concentrated vinegar), essential oils, and natural allelochemicals, are nonselective contact herbicides most useful for spot treatments of, for example, a localized infestation by a new weed species, or poison ivy on fencerows or near a farm stand. The **Organic Materials Review Institute** (http://www.omri.org) lists products that are allowed and those not allowed for use on organic farms, including herbicide products. A few bioherbicides based on specific fungal pathogens have been developed against specific weed species that have become especially problematic in particular regions. At this time, however, organic herbicides and bioherbicides play a minor role in the organic weed control toolbox. See the related article **Can I Use This Input On My Organic Farm?** (/pages/18321/can-i-use-this-input-on-my-organic-farm) for further information.

Biological Weed Control

Several other biological agents that can potentially contribute to weed control in organic farming systems include allelopathic cover crops, weed seed consumers, soil microorganisms, insects, and farm animals including weeder geese. For more on the utilization of biological agents and processes in weed control, see the article, **Utilize Biological Processes to Further Reduce Weed Pressure** (/pages/18548/utilize-biological-processes-to-further-reduce-weed-pressure) .

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables** (/pages/18539/twelve-steps-toward-ecological-weed-management-in-organic-vegetables) . See also **Design the Cropping System and Select Tools for Effective Weed Control** (/pages/18531/design-the-cropping-system-and-select-tools-for-effective-weed-control) , and the following video clips:

- Video: Vegetable Farmers and their Weed-Control Machines (/pages/18436/video:-vegetable-farmers-and-their-weed-control-machines)
- Video Clip: Weed Em and Reap Part 1. Lely Tine Weeder (/pages/18403/video-clip:-weed-em-and-reap-part-lely-tine-weeder)
- Video Clip: Weed Em and Reap Part 1. Reigi Weeder (/pages/18327/video-clip:-weed-em-and-reap-part-reigi-weeder)
- Video Clip: Weed Em and Reap Part 1. Retractable Blade Cultivator (/pages/18328/video-clip:-weed-em-and-reap-part-retractable-blade-cultivator)
- Video Clip: Weed Em and Reap Part 1. Wiggle Weeder (/pages/18401/video-clip:-weed-em-and-reap-part-wiggle-weeder)
- Video Clip: Weed Em and Reap Part 1. Filled-Furrow Squash Cultivator (/pages/18404/video-clip:-weed-em-and-reap-part-filled-furrow-squash-cultivator)
- Video Clip: Weed Em and Reap Part 1. Hayrake (/pages/18402/video-clip:-weed-em-and-reap-part-hayrake)
- Video Clip: Weed Em and Reap Part 1. Mulched Garlic (/pages/18400/video-clip:-weed-em-and-reap-part-mulched-garlic)
- Video Clip: Weed Em and Reap Part 1. Mulched Rhubarb (/pages/18399/video-clip:-weed-em-and-reap-part-mulched-rhubarb)
- Video Clip: Weed Em and Reap Part 1. Paper Mulch (/pages/18398/video-clip:-weed-em-and-reap-part-paper-mulch)

- Video Clip: Weed Em and Reap Part 1. Tips on Flaming (/pages/18392/video-clip:-weed-em-and-reap-part-tips-on-flaming)
- Video Clip: Weed Em and Reap Part 1. Ceramic Plate Flamer (/pages/18394/video-clip:-weed-em-and-reap-part-ceramic-plate-flamer)
- Video Clip: Weed Em and Reap Part 1. Shielded Row Flamer (/pages/18396/video-clip:-weed-em-and-reap-part-shielded-row-flamer)
- Video Clip: Weed Em and Reap Part 1. Shielded Bed Flamer (/pages/18397/video-clip:-weed-em-and-reap-part-shielded-bed-flamer)
- Video Clip: Weed Em and Reap Part 1. Reflective Shield Flamer (/pages/18395/video-clip:-weed-em-and-reap-part-reflective-shield-flamer)
- Video Clip: Weed Em and Reap Part 1. Insulated Shield Flamer (/pages/18393/video-clip:-weed-em-and-reap-part-insulated-shield-flamer)

References and Citations

- Astatkie, T., M. N. Rifai, P. Havard, J. Adsett, M. Lacko-Bartosova, and P. Otepka. 2007. Effectiveness of hot water, infrared and open flame thermal units for controlling weeds. Biological Agriculture and Horticulture 25: 1–12.
- Bowman, G. (ed.) 1997. Steel in the field: A farmer's guide to weed management tools. Sustainable Agriculture Network Handbook Series Book 2. National Agricultural Laboratory, Beltsville, MD. (Available online at: http://www.sare.org/publications/steel/index.htm (http://www.sare.org/publications/steel/index.htm)) (verified 11 Dec 2008).
- Diver, S. 2002. Flame weeding for vegetable crops [Online]. National Sustainable Agriculture Information Service. Available at: www.attra.org/attra-pub/flameweedveg.html (http://www.attra.org/attra-pub/flameweedveg.html) (verified 21 Nov 2008).
- Mohler, C. L. 2001. Mechanical management of weeds. p. 139–209. *In* M. Liebman, C. L. Mohler, and C. P. Staver. Ecological management of agricultural weeds. Cambridge University Press, New York.

Further Reading

- Vegetable farmers and their weed-control machines (/pages/18436/video:-vegetable-farmers-and-their-weed-control-machines) [DVD]. V. Grubinger and M.J. Else. 1996. University of Vermont Extension. Available for purchase at http://www.uvm.edu/vtvegandberry/Videos/weedvideo.htm (http://www.uvm.edu/vtvegandberry/Videos/weedvideo.htm) (verified 31 Dec 2008).
- Weed 'Em and Reap Part 1: Tools for non-chemical weed management in vegetable cropping systems (/pages/18329/video:-weed-em-and-reap-part-tools-for-organic-weed-management-in-vegetable-cropping-systems) [DVD]. A. Stone. 2006. Oregon State University Dept. of Horticulture. Corvallis, Oregon. Available for purchase at: http://www.weedemandreap.org (http://www.weedemandreap.org) (verified 17 Dec 2008).

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University of Minnesota
Extension
Service

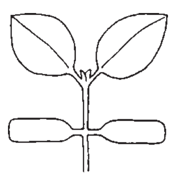
Broadleaf and Grass Weed Seedling Identification Keys

Beverly Durgan, Weed Scientist
Department of Agronomy and Plant Genetics
College of Agricultural, Food, and Environmental Sciences

BROADLEAF WEED SEEDLING IDENTIFICATION KEY

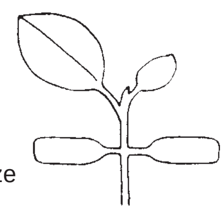
TERMINOLOGY

Opposite Leaves



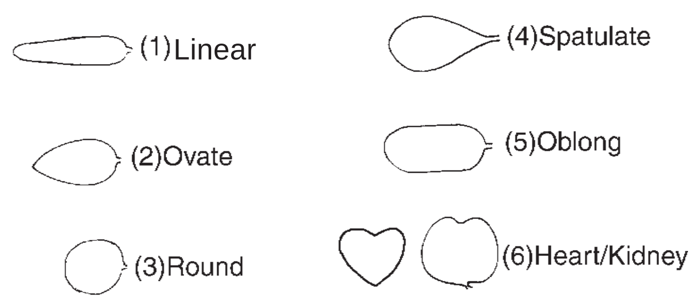
Attached at same node on opposite sides of stem. Leaves at the same node are of similar size.

Alternate Leaves

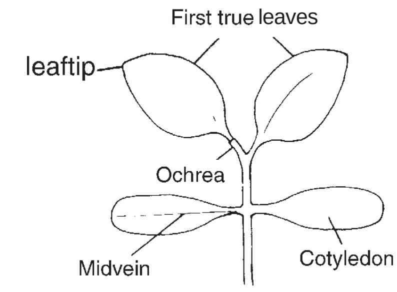


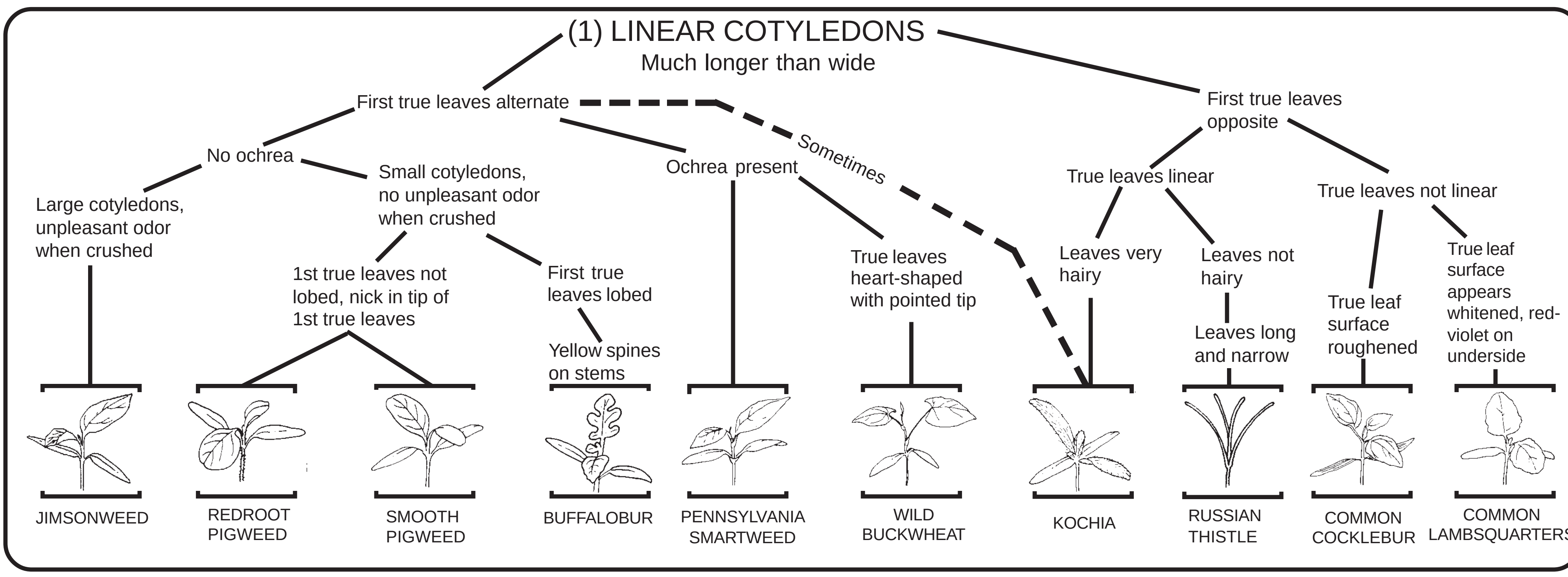
One leaf per node. Leaves increase in size from top to bottom.

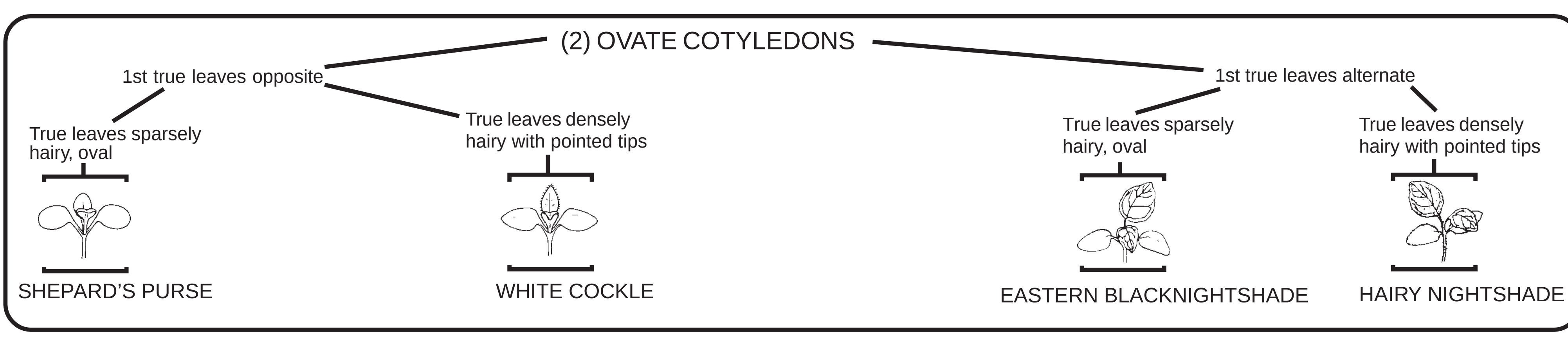
Cotyledon Shapes

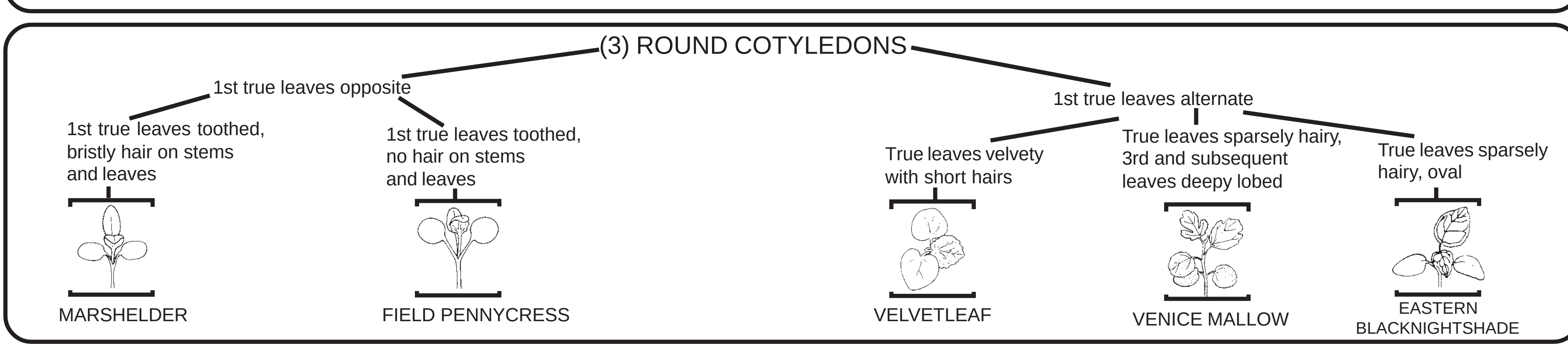


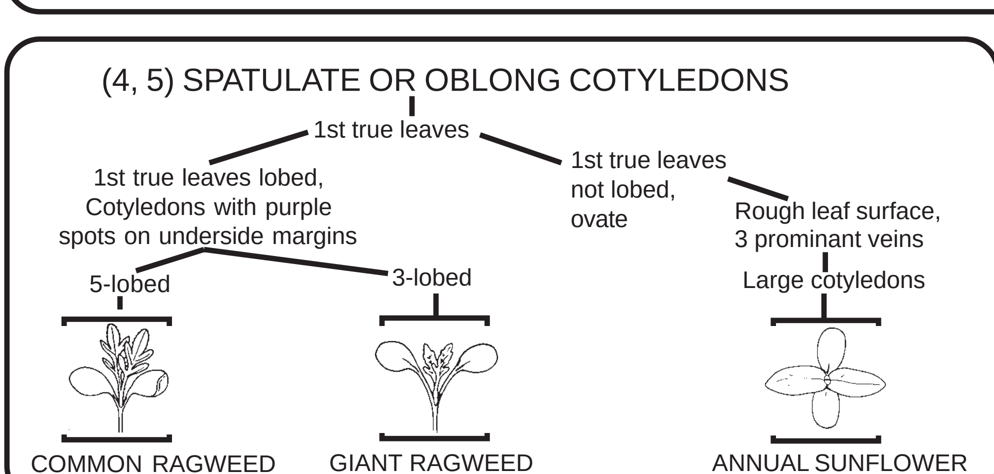
Vegetative Broadleaf Plant Parts

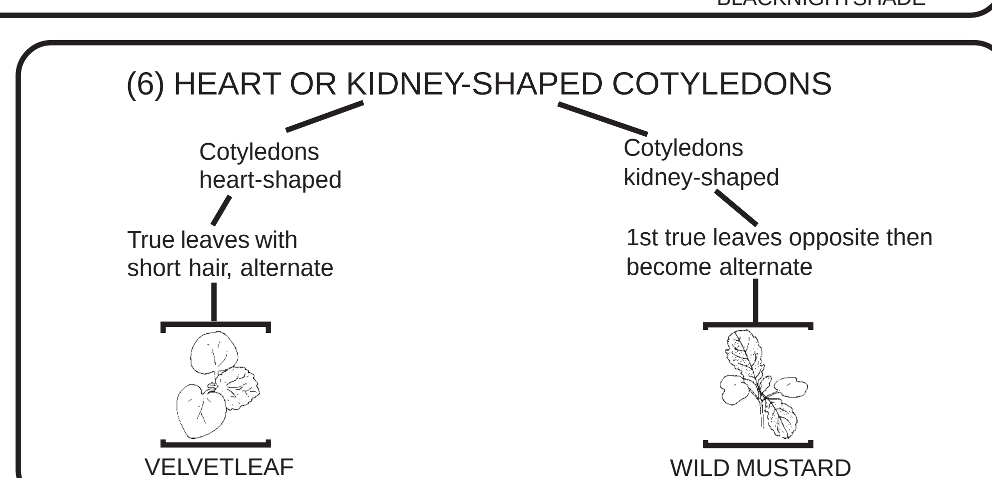












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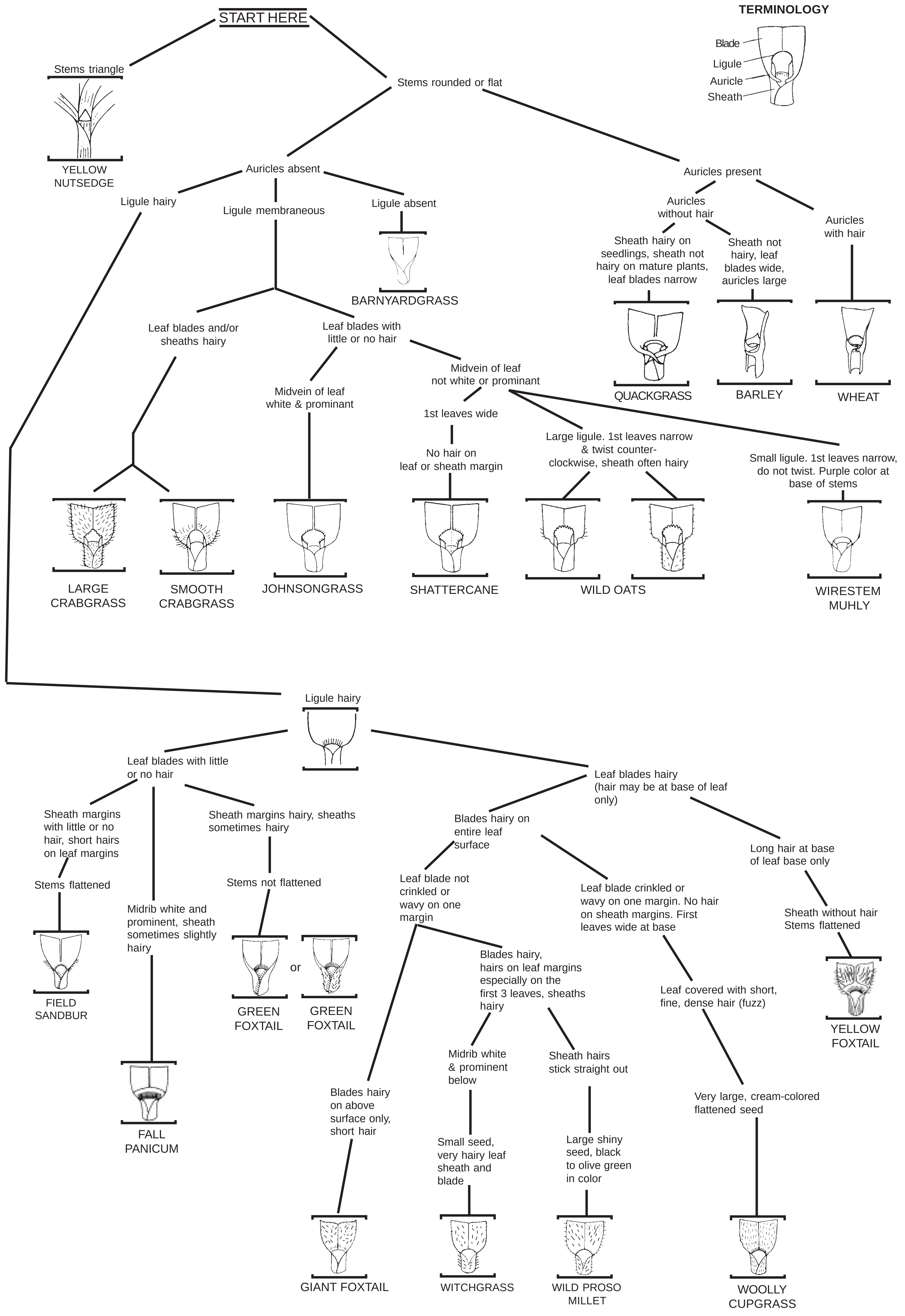
GRASS WEED SEEDLING IDENTIFICATION KEY



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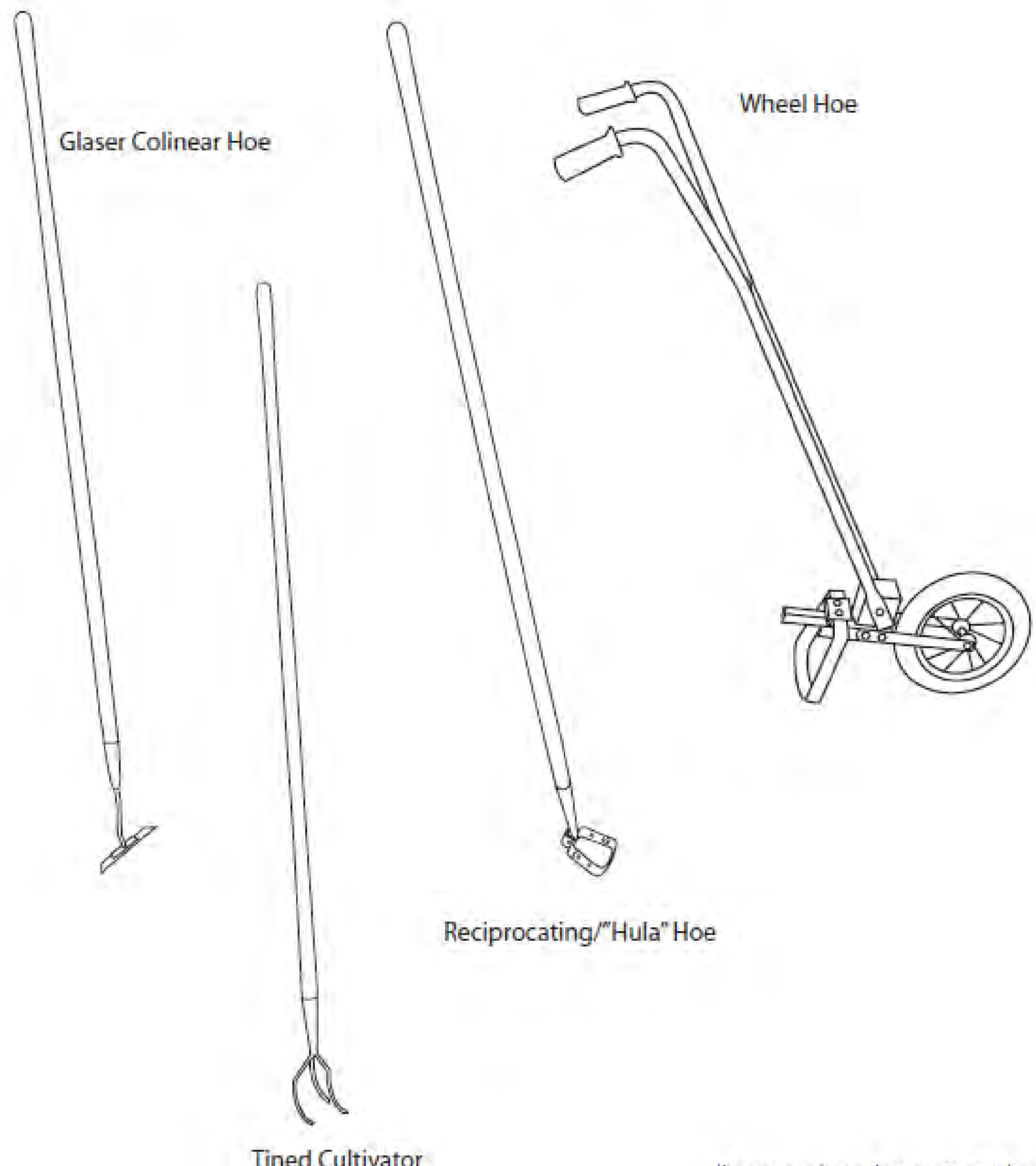
3. *Create and maintain a size differential between the crop and the weeds to facilitate mechanical weed control.* Stale seedbed or preemergence cultivation delays weed emergence relative to the crop. Subsequent cultivations can increase in depth and degree of soil movement as the crop grows larger. Once they are well established, some vegetable crops like potatoes and sweet corn tolerate soil being thrown into the rows to bury small in-row weeds. However, this works well only if weeds that emerged shortly after crop planting have been killed by earlier cultivations.
4. *Cultivation becomes less effective as weed density increases*—for several reasons. First, the proportion of weeds that escape cultivation is approximately constant over a wide range of weed densities. Therefore, a high initial weed density means a higher density of escapes, which can reduce yields. With low initial weed density, escapes have little impact on robust crops, and can be pulled manually out of weed-sensitive, high value crops. Second, soil clings better to the dense mass of roots characteristic of high weed populations than to individual root systems of more isolated weeds. Many implements do not penetrate as well when roots bind the soil together. Third, a high weed density that forms a continuous cover of green plant tissue can "lubricate" the soil surface, which further interferes with the uprooting action of cultivation implements. As a result, the weeds reroot and resume growth more readily.
5. *Effective cultivation requires good tilth, careful seedbed preparation and good soil drainage.* A loose, fine tilth facilitates stripping soil from weed roots, and reduces the risk of knocking over crop plants with larger clods when soil is thrown into the row. Shallowly working tools such as tine weeders are relatively ineffective in cloddy or compacted soil, because movement of clods may facilitate emergence of weed seedlings from below the clods, and fail to kill weed seedlings within clods. Timely cultivation depends on adequate soil drainage, especially in wetter than normal seasons.
6. *Cultivation (and tillage) in the dark stimulates germination of fewer weed seeds than cultivation in daylight.* Tillage and cultivation at night, or with implements that are covered with light-excluding canopies, can reduce the density of later-emerging weeds,

especially in small-seeded broadleaf species. However, since not all seeds in the seed bank require light to germinate, and some will be left near enough to the surface to receive light *after* cultivation, dark cultivation does not *eliminate* the flush of weed emergence. Consider using light- and dark cultivation to manipulate timing of weed emergence. For example, do primary tillage in the light, let weeds emerge, then prepare and plant the final seedbed in the dark. After planting, first perform shallow full-field cultivation in the dark to minimize weeds in the crop row, then do early interrow cultivations in the light to draw down the seed bank, then do a final dark interrow cultivation.

7. *Time cultivations relative to changing weather and soil conditions to optimize effectiveness.* For example, aim to cultivate early in the day during hot, dry weather, so that uprooted weeds desiccate and die before they can reroot. In particular, avoid rotary hoeing while the ground is wet, which makes this implement ineffective. Flame weeders work best when leaf surfaces are dry, so wait until dew has fully evaporated.

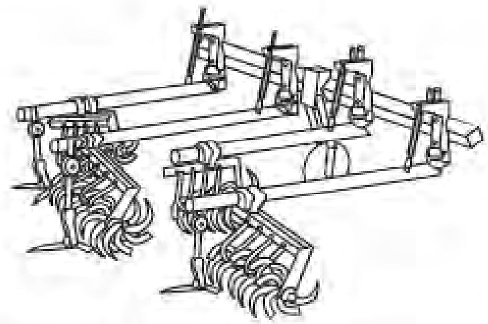
Hand Tools for Weed Management



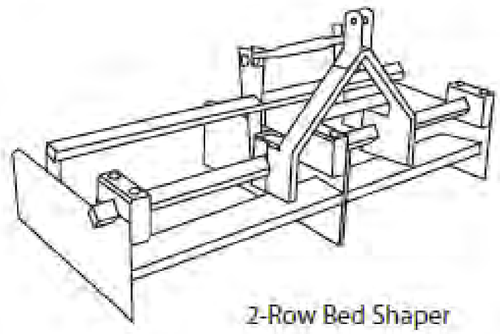
illustrations by Cathy Genetti Reinhard; not to scale

From "Teaching Organic Farming and Gardening"
University of California, Santa Cruz

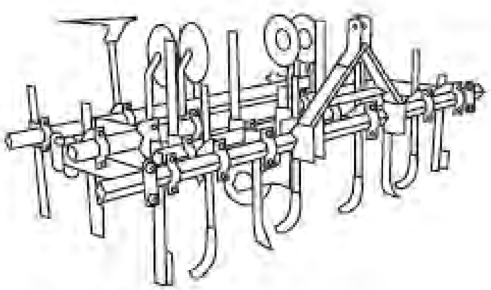
Tools for Mechanical Weed Management



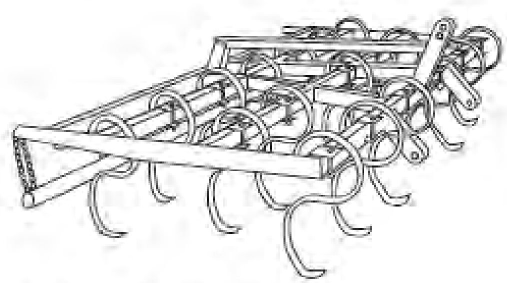
Lilliston Cultivator



2-Row Bed Shaper



3-Bar Cultivator



Spring-toothed Harrow

Illustrations by Cathy Genetti Reinhard; not to scale

Plant Disease Basics

What is a plant disease?

A plant disease is a dynamic process where a living or non-living entity interferes with the normal functions of a plant over a period of time. Things that happen just once, like lawnmower blight or lightning strikes, are not considered diseases, but rather an injury. Plant diseases result in visible symptoms which can help diagnose the disease or disorder.

Why are plant diseases important?

Usually, farmers are worried about the financial losses that plant diseases can cause because of reduced quantity and/or quality of the product. For example, in 1970 U.S. farmers lost $1 billion dollars to an epidemic of southern corn leaf blight. Disease epidemics can also threaten entire plant species. Historical examples of destructive plant disease epidemics include American chestnut blight and Dutch elm disease [1].

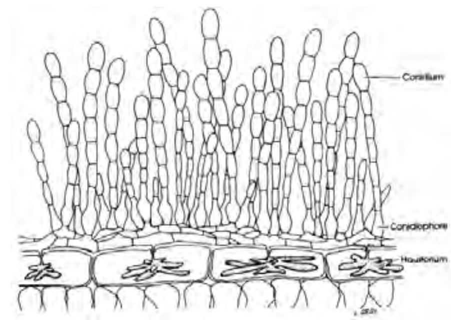
What causes plant disease?

Pathogens like bacteria, fungi, nematodes, viruses, phytoplasmas as well as abiotic problems can all cause plant diseases.

Abiotic problems are caused by adverse extremes in the environment, i.e., nutrient deficiency, prolonged water stress and air pollution.

Bacteria are single-celled organisms with no nucleus. Most bacteria associated with plants are saprophytic (feed on dead organic debris) and do no harm to plants. But a few, around 100 species, can cause plant diseases [2]. Under favorable conditions, they reproduce very quickly, some doubling their population in just 9.8 minutes [3]. Think of the pink goo that grows on rice left in the refrigerator for too long. These are bacteria. Bacteria can cause blights, leaf spots, fruit rots, vascular wilts and galls. They typically enter the plant through natural openings such as hydathodes and lenticels or wounds created by wind-swept sand, hail, heavy rain and/or mechanical damage. They can be spread by infected seed or from plant to plant by water splashing, insects and humans.

Microscopic worms called nematodes can attack plant roots. Root knot nematode affects tomatoes (pictured above) and many other crops.



Fungi form chains of cells. They can grow like tiny threads through the soil or plant cell walls. Most comsume dead plant material, but some can use enzymes to dissolve and digest living plant tissue.

Drawing by Lenore Gray.

Some bacteria, like bacterial wilt, affect the phloem of plants, clogging the tubes that move water and nutrients.

Fungi usually grow as threads or strands called hyphae. A single hypha can be only a few inches long or miles long. Mushrooms are one type of fruiting body that some fungi form to reproduce. Fungi reproduce via the production of spores. These spores may be spread long distances by air or water, or they may be soil borne. Certain fungi are also able to produce structures that enable them to survive in the soil for many years. They can cause root and stem rots, shoot and leaf blights, leaf spots, cankers, vascular wilts and post-harvest storage rots [1].

Nematodes are tiny microscopic round worms that generally live most of their lives in the soil. Plant-pathogenic nematodes comprise only a very small sub-set of all the nematode species. These nematodes have a needle-like mouthpart called a stylet used to pierce the plant cells and feed on the cell contents. Feeding either kills the plant cells, leading to the development of lesions or causes galls to develop on the roots, reducing the ability of the plant to take-up water and nutrients.

Viruses particles are pieces of RNA or DNA with a protein coat. They multiply by inducing host cells to form more virus particles. Viruses are spread through vegetative propagation (i.e., cuttings, grafting, etc.), seed, insects (most common) or nematodes. Typical symptoms include stunting, mosaic or ring-spot patterns on leaves and fruit.

Phytoplasmas are specialized bacteria without a cell wall that depend on the host plant to survive. Typically transmitted by insects during feeding, they live in the plant sap and clog up the vascular system reducing the ability of the plant to move water or nutrients. A typical symptom is phyllody, the production of leaf-like structures instead of flowers, or a witch's broom or bushy appearance.

How do pathogens cause disease?

Pathogens use a number of different strategies to enter their host and capture the plant's energy for their own use. Some enter through natural openings or wounds created by mechanical damage or from severe weather events (i.e., hail, wind-swept sand). Others, such as some fungi or nematodes, can directly penetrate through the plant tissue, while viruses rely primarily on insects for transmission. Once inside the plant, some pathogens use enzymes that break down the tissue of the plant just like the enzymes in our stomachs break down food. Others have toxins that actually kill the plant tissue before the enzymes break it down. Still others secrete hormones that change the way the plant grows. For example, the hormones may tell the plant to move more nutrients to the area where the pathogen is lodged. All viruses and a few bacteria force the plant to produce pathogen gene products. Since the plant is putting most of its energy into making more viruses, the cells starve [4].

1. Agrios, G.N., *Plant Pathology*. Vol. 4. 1997, San Diego: Academic Press.
2. Jackson, R.W., *Plant Pathogenic Bacteria: Genomics and Molecular Biology.* 2009: Caister Academic Press.
3. Eagon, R.G., *Pseudomonas natriegens, a marine bacterium with a generation time of less than 10 minutes.* Journal of Bacteriology, 1972. 83(4): p. 736-7.
4. Miles, A. and M. Brown, *Teaching Organic Farming and Gardening: Resources for Instructors*. 2007, Santa Cruz, CA: University of California Farm and Garden.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, and Beth Krueger Gugino, Penn State Department of Plant Pathology. Reviewed by Emelie Swackhamer, Penn State Extension. Adapted from "Teaching Organic Farming and Gardening" [4]. Last updated June 2011.

Diagnosing a Plant Problem 101

Something is wrong with your plant. What is the cause? Don't assume you know the answer and accidently treat for the wrong problem. Use this step -by-step method to narrow down the possibilities.

There can be numerous causes for a symptoms; not all symptoms are related to insects or diseases. Plant health may be affected by soil fertility and texture, weather conditions, quantity of light, other environmental and cultural conditions, as well as animals, including humans. In addition, complexes can develop from interactions between two or more of these factors.

Unlike Sherlock Holmes mysteries, there are generally not unlimited possibilities, however, it will take your observational skills and deductive logic to help solve the mystery.

Keep in mind that this is a skill that takes time to develop and it is always best to verify your conclusions by bringing a sample to your local Extension Office or by sending a sample to your local plant diagnostic clinic. Penn State offers this service for free (except commercial turf samples). Take advantage of it. For a listing of local Extension Offices see http://extension.psu.edu. For the plant diagnostic clinic address information, see reference [1].

Know the normal appearance of the plant. You have to know what the plant is supposed to look like before you know that something is wrong. For example, some plants have variegated foliage or are yellow-green. They are not diseased. They are supposed to look that way.

Consult literature resources for possible diseases and disorders. There are many resources that list common pathogens and disorders for different types of plants. It is important to review a resource that is specific to your geographic area. You are unlikely to have a plant disease that is only found in Florida in your market garden in Pennsylvania. Some good resources are the *Organic Production Guides* [2] for a listing of common problems in the Northeast by crop; the *Northeast Vegetable and Strawberry Pest Identification Guide* [3] and *Identifying Diseases of Vegetables* [4] for pictures. Learning potential problems commonly associated with a particular crop beforehand will be beneficial during the busy

Don't be fooled. Plants like this variegated thyme may look sick even when they are not.

Know which problems are common for your crop and cultivar by consulting the literature.

Ozone damage in pumpkins. The problem did not get progressively worse, suggesting an abiotic culprit.
Photo Beth Krueger Gugino, Penn State University.

growing season.

Investigate symptom progression. You want to know if the problem is a result of a living (biotic) or non-living (abiotic) factor. Usually biotic diseases spread throughout the plant and from plant to plant as the pathogen reproduces and attacks new tissue. Abiotic problems tend not to spread this way.

Ask questions (similar to those a doctor would ask you):

1. When was the problem noticed?
2. Was the damage sudden or gradual?
3. How old are the affected plants?
4. What percentage of the plant is affected?
5. How severe is the injury?

Observe patterns. Is a large area affected or just scattered plants? Check to see whether the distribution pattern is uniform or random. Are the symptoms first observed in one field corner or along a field edge or are they associated with the lowest or highest areas of the field? Uniform distribution, especially across different plant types, usually suggests an abiotic problem, but it could also indicate seed-borne or transplant problems.

Review your cultural practices. Sometimes what we think is a disease is really a problem related to irrigation or fertility practices. Over-fertilization or over-watering cause problems as often as under-fertilization or under-watering. Also consider the soil conditions and field cropping and/or pesticide application history.

Consider possible environmental causes:

1. Temperature extremes
2. Drought or excess rain
3. Soil types and conditions

Check host specificity. Are the symptoms present on just one species or variety of plant? If plants from many different families were affected, such as lettuce, tomatoes, flowers and turnips, then it is more likely to be an abiotic problem.

Check for signs and symptoms of plant pathogens and diseases. Signs are the actual plant pathogen visible on the symptomatic plant, e.g., masses of powdery mildew spores. Symptoms are changes in the appearance of the plant in response to infection by the pathogen, e.g., wilting or chlorosis. Go back to your resources and try to solve the puzzle.

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension; Beth Krueger Gugino, Penn State Department of Plant Pathology. Reviewed by Emelie Swackhamer, and Lee Stivers, Penn State Extension. Last updated December 2011.

Chilling injury in corn. The most stressful condition for germinating corn seeds is exposure to cold (< 50º F), wet conditions immediately following planting. When the seed takes in cold water, that reduces the elasticity of the cellular membranes of the developing seedling. This can cause cell rupture and leakage, which can release sugars and promote fungal and insect damage to the seed.

Photo G. Roth, Penn State University.

Early blight signs and symptoms typically start on leaves closest to the soil indicating that the pathogen spreads from crop debris in the soil.

Photo Beth Krueger Gugino, Penn State University.

1. *Penn State Plant Disease Clinic*. http://www.ppath.cas.psu.edu Plant_Disease_ Clinic.htm [cited 2011 March].
2. Abawi, G.S., et al., *2010 Production Guide for Organic Cole Crops*, A. Seaman, Editor. 2010, Cornell University, New York State Department of Agriculture and Markets, Integrated Pest Management.
3.Bonanno, A.R., et al., *Northeast Vegetable and Strawberry Pest Identification Guide*. 2009, Northeast Extension.
4. MacNab, A.A. et al. *Identifying Diseases of Vegetables,* Penn State College of Agricultural Sciences, University Park, PA.

Ecological Disease Management

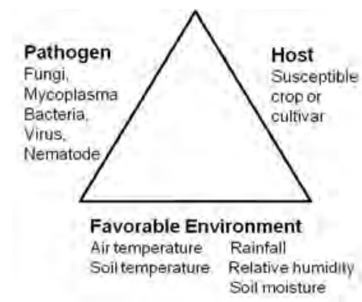
In order for a plant to become diseased, there are three conditions that must be present. There must be a pathogen, a favorable environment where the pathogen can thrive, and a susceptible host. All of the strategies that we use to manage plant diseases work to remove or limit one of these factors, thus breaking the plant disease triangle.

Manage the Pathogen

Exclusion. Keep the pathogens out! Make sure that your seeds and transplants are pathogen-free. The epidemic of late blight in Pennsylvania in 2009 was partially the result of the widespread distribution of the pathogen on infected transplants and the cool, wet conditions that persisted during the growing season. Consider growing your own transplants or inspect them carefully before you bring them to the farm. Saving seed can easily carry over pathogens from the previous year. Only save seed from healthy plants to reduce this risk. Although pathogens may occasionally be introduced from a commercial seed source, generally they are the most reliable source [3]. It is also essential to keep your equipment and stakes clean and sanitized. You don't want to be the grower who has bacterial spot in your peppers every year because you re-use your stakes without sanitizing them. Sodium hypochlorite at 0.5% (12 times dilution of household bleach -- note that household bleach contains additives and is not allowable for certified organic) is effective, and must be followed by rinsing, and proper disposal of solution. Hydrogen peroxide is also effective [4]. Prior to sanitizing, remove visible organic debris from the stakes and/or equipment. Organic matter can quickly neutralize surface disinfectants rendering them ineffective. Also, change solution when it becomes visibly dirty for the most effective results. *Note these materials are on the list of allowed substances for certified organic production. However, it is important, even for allowed materials, to list them on your organic system plan. Any materials you use on certified farms must be cleared with your certifier before use prevent mis-haps that could result in losing certification.*

Eradicate or reduce the inoculum. Crop rotation between plant families can help keep the levels of disease down. Rotating to remediate a disease problem can be challenging,

The Disease Triangle



Rotations that includes a fallow period can be the key for controlling some pathogens that have a wide host range.

Bacterial spot on tomato can spread from debris on re-used tomato stakes.

Photo courtesy Beth Krueger Gugino, Penn State University.

especially if the pathogen is long-lived in the soil and/or has a wide host range. Rotating between unrelated crops such as beans to sweet corn, lettuce to cucurbits, and cucurbits to crucifers can help avoid the build-up of soil-borne pathogens [3]. For example, Northern root-knot nematode is a fairly common problem that attacks carrots and potatoes, in addition to a number of other vegetable crops. In a study in New York, when field corn (which is not a host to the nematode) was included in the rotation, the number of nematodes was greatly reduced. In general, grasses (monocots) are not susceptible to the same diseases as vegetables (dicots). Adding sweet corn, wheat or a grass cover crop to your rotation can reduce soil-borne disease problems. A good rule of thumb is no crop family should return to the same field or bed for a minimum of three years to avoid soil-borne disease build-up. Beware, some pathogens create special survival structures that allow them to survive in the field for much longer. See reference [2] for a detailed description of rotation recommendations for different pathogens and crops.

Many pathogens can survive on debris over the winter. Tilling in plant residue at the end of the season allows soil micro-organisms to break the material down, leaving potential pathogens without a host.

Antagonistic plants. Certain plants, such as mustards and sudangrass, can kill plant pathogens that live in the soil. They contain a chemical and an enzyme in their plant tissue, specifically their cell wall. When you mow the plant and crush the tissue, the enzyme reacts with the chemical creating a toxic gas; same as a fumigant. If you quickly incorporate this crushed plant material into the soil after mowing, the volatilized chemical can kill plant pathogens, nematodes and weed seeds [5]. Farmers in Northampton County tried this method to control plant-parasitic nematodes. They learned that the process can be tricky. You need to make sure you have the right varieties, enough moisture, adequate fertility and good timing to get the result you want.

Hot water treatments. If you think your seed might be affected by plant pathogens, you can use a hot water bath that will both surface disinfect as well as kill pathogens within the seed. For example, hot water treatment for eggplant submerses seeds in 122°F water for 25 minutes. Be careful to find out the correct temperature and length of time for the treatment. Too cold will not work and too hot will kill the seed [1].

Create an Unfavorable Environment

Keep leaves dry. Most fungi and bacteria that kill plants require wet environments from dew, rain or irrigation to infect and cause disease. If you want to keep them from reproducing,

How to Hot Water Treat Seed [1]:

Step 1: Wrap seeds loosely in a woven cotton bag (such as cheesecloth) or nylon bag.

Step 2: Pre-warm seed for 10 minutes in 100°F (37°C) water.

Step 3: Place pre-warmed seed in a water bath that will constantly hold the water at the recommended temperature (see table that follows). Length of treatment and temperature of water must be exactly as prescribed.

Step 4: After treatment, place bags in cold tap water for 5 minutes to stop heating action.

Step 5: Spread seed in a single, uniform layer on screen to dry.

122°F 25 min	**122°F 20 min**
Brussels sprouts, eggplant, spinach, cabbage, tomato	broccoli, cauliflower, carrot, collard, kale, kohlrabi, turnip
125°F 30 min	**118°F 30 min**
pepper	lettuce, celery

don't give them the environment they like. Good air circulation and drip irrigation help keep the leaves dry and the diseases out. For example, grey mold in tomatoes is generally not a problem in the field. But, when you pack tomatoes in a high tunnel with little air circulation it becomes common, especially within the lower portion of the plant.

Maintain high quality soil. Balanced fertility, good drainage and good soil tilth will all help promote a diverse range of soil micro-organisms. Diverse microbial communities generally compete with plant pathogen organisms in the soil and help keep your plants healthier. Additionally, plants that are not stressed are less susceptible to disease.

Manage weeds. Many weeds are also hosts for diseases. When your crop is surrounded by weeds, the atmosphere tends to be moist, favoring infection.

Choose a Less Susceptible Variety

Using disease resistant varieties is one of the most economical and reliable methods of disease management. Resistant varieties are not available for all diseases of vegetable crops, but they definitely should be considered. Dr. McGrath from Cornell maintains an excellent list of disease resistant cultivars, see reference [6]. Your seed catalog will also list disease resistance. Note the letters DM, PM, etc., after each cultivar. They are codes to tell you which diseases the cultivar is resistant to. It is important to become familiar with common vegetable diseases in your region.

Resistant varieties are rarely immune to the disease. They do help delay the onset of disease development, therefore, potentially increasing your yields and allowing your crop to fully mature.

Pest Management Materials

Early detection is important for successful disease management. Make sure you scout plants regularly and know which diseases are present in the crop. When preventive and cultural methods for disease control are insufficient to manage a disease, National Organic Program (NOP) compliant inputs can be applied.

NOTE: Before applying ANY pest control product, be sure to: 1) read the label to be sure that the product is labeled for the crop and the disease you are trying to manage, 2) read and understand the safety precautions and application restrictions, and 3) make sure that the brand name product is listed in your Organic System Plan and approved by your certifier.

Crop rotation affects pathogen persistence

Clubroot, caused by *Plasmodiophora brassica*, can be a significant problem in brassica crops. The pathogen can survive in the soil for over seven years, even in the absence of mustard family crops or weeds. But clubroot tends to decline more quickly when tomato, cucumber, snap bean and buckwheat are grown. Clubroot was effectively controlled by growing aromatic herbs including peppermint, garden thyme and summer savory for two to three consecutive years [2]. For some brassica crops, resistant varieties are also an option.

For details on the efficacy of organic pesticides, see recommendations from the "Organic Production Guide" appropriate for your crop. See references [4, 7].

References

1. Miller, S.A. and M.L. Lewis Ivey, *Hot Water and Chlorine Treatment of Vegetable Seeds to Eradicate Bacterial Plant Pathogens.* Ohio State University Extension.
2. Mohler, C.L. and S.E. Johnson, eds. *Crop Rotation on Organic Farms -- A Planning Manual*. 2009, Natural Resource Agricultural and Engineering Service, NRAES, Cooperative Extension: Ithaca, NY. http://www.sare.org/publications/croprotation/croprotation.pdf.
3. Reiners, S. and C.H. Petzoldt, eds. *Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production*. 2005, Cornell Cooperative Extension.
4. Caldwell, B., et al., *Resource Guide for Organic Insect and Disease Management*. 2006, Ithaca, NY: Cornell University.
5. McGuire, A., *Mustard Green Manures, On Farm Research Results.* Washington State University, 2001.
6. McGrath, M., *Tables of Disease Resistant Varieties*. http://vegetablemdonline.ppath.cornell.edu/Tables/TableList.htm [cited 2011 March].
7. *Organic Production Guides*. New York State IPM and Cornell University. http://www.nysipm.cornell.edu/organic_guide/ [cited 2011 March].

Prepared by S. Tianna DuPont, Sustainable Agriculture Educator, Penn State Extension, and Beth Krueger Gugino, Penn State Plant Pathology. Reviewed by Emelie Swackhamer, Penn State Extension, and Lee Rinehart, Pennsylvania Certified Organic. Last updated December, 2011.

Branch Creek Farm, Perkasie PA — Disease Management

Mark and Judy Dornstreich have been farming for over 30 years in beautiful Bucks County, PA. They produce baby greens, specialty vegetables and edible flowers year-round in 3 greenhouses. Come summer, they shift their attention out to the field where they grow unique vegetable varieties on about 5 acres. They provide Philadelphia and New York City restaurants with only the highest quality, mouth-watering produce.

Greenhouses

Systems ensure employees consistently practice good sanitation. For instance, employees mix soil into clean buckets, which are a different color than the buckets used for removing compost/plant debris. From there, the soil goes into sanitized trays or thoroughly cleaned permanent wooden beds for seeding. If there was a disease in either structure, it gets taken out of the greenhouse and sanitized before being brought back into the house. Color-coded sticks are placed in the beds so employees know what measures they need to take when cleaning out an old bed.

Mini-Crop Rotations

Every time a greenhouse bed is seeded with a new crop, a corresponding tag gets placed in the bed. Once the old crop has been cleaned out of the beds and the beds have been re-filled with the new propagation mixture, the next crop can be planted. Before seeding the new crop, employees check to see what the last crop was. They avoid seeding similar families simultaneously. They don't seed a bed of chard where there just was one. Instead, they seed something from a different plant family, like a mustard or a salad green. “There are certain crops we consider to be the ‘canary in the coal mine’” says Mark. Cress is one of those plants. It begins to yellow and by the next day the entire bed is dead. That means there is a disease in the box it's planted in and that bed needs to be taken out of production for awhile.

Sanitation

Frequently weeding the floors of the greenhouses not only prevents new weeds, but also means no hiding spots for disease/virus vectoring pests, such as aphids. The majority of the beds in the greenhouses can be moved by two people. Workers will periodically shift the beds one by one down the benches to clean in between the beds. This gets rid of various debris, insects, fungi, and dirt which could potentially cause issues if left over time.

Air circulation

Mark's philosophy when it comes to temperature and humidity levels in the greenhouses is "if I'm uncomfortable- so are the plants". Louvre vents are in place in both ends of the greenhouses to allow fresh air into the house when the temperature rises. Also, fans are in place throughout the house to push the air from one end to the other. This cuts down on humidity and also chances of a fungal disease taking hold. Another way to increase air circulation between individual plants is to avoid seeding them too densely. This is a challenge for micro-greens growers because the spacing has to be close in order for the individual bed/crop to turn a profit.

Watering

"The person holding the watering wand is the same person holding your checkbook" laughs Mark. Watering is the most important skill a greenhouse employee can have. Under or over-watering can have devastating effects on a crop. Under-watering results in stressed/stunted growth while overwatering creates the perfect environment for disease. The beds are hand watered in the morning and mid-afternoon. This gives the foliage a chance to dry before it gets too cool. It's done by hand so that beds can be watered individually and only when necessary. The biggest challenge Branch Creek faces is that there are too many employees who take the watering upon themselves when it's not necessarily needed. "You can't tell people not to water when they think something looks dry- you'd have an even bigger problem on your hands then."

In the field

Mark doesn't face too many disease issues out in the field. Most of the problems mentioned above are taken care of naturally by environmental conditions. "I think of wind as a form of plant exercise" says Mark. It strengthens them and takes care of the ventilation issue. As far as watering out in the field goes, Mark recommends that you aim for watering the roots/soil, avoid getting the foliage wet to prevent the spread of disease.

Crop Rotation

The field crops, mainly tomatoes, peppers and eggplant, are rotated every season. Mark prefers to grow tomatoes in the hoophouses because it keeps the fruit clean and the plants healthy. Rotating tomatoes between the houses gets harder every year, because it seems that almost every house had tomatoes in it last year. His solution-build another hoophouse!

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Aston Ward, Penn State Extension. Photos taken by Aston Ward, courtesy of Branch Creek Farm. Last updated May 2011.

Penn State **Extension**

Plant problem scouting checklist

- ✓ What is the effected host?
- ✓ When was the problem noticed?
- ✓ Was the damage sudden or gradual?
- ✓ How old are affected plants?
- ✓ Percentage of plant affected?
- ✓ What is the degree of injury?
- ✓ Prevalence of the problem – large areas or scattered
- ✓ Distribution of symptoms – Uniform (abiotic) Random (biotic)
- ✓ Are there different hosts with the same problem?
- ✓ Signs? Describe
- ✓ Symptoms? Describe

Late Blight Devastates Northeast Tomato Crops

By Emily Brown Rosen
Policy Director, Pennsylvania Certified Organic

The Northeast has been hit by the devastating vegetable disease known as Late Blight, (*Phytopthera infestans*) on tomatoes and potatoes. Dr. Meg McGrath, plant pathologist from the Cornell Univ. Long Island Extension Center, points out that this Latin name is apt: it means "plant destroyer". This is the same pathogen that caused the Irish potato famine back in the 1840s. Normally late blight hits our region rarely, and late in the season, but this year it is widespread. Penn State reported it had been confirmed in at least 26 counties by the end of July. Tomato transplants grown in the south and shipped to "big box" stores all over the Northeast were apparently infected with late blight. The disease turned up in home gardens all over the region, and the cool wet weather this June enabled wide dispersal of the deadly spores.

What does it look like?

The first symptoms of Late Blight on tomatoes are small, dark, circular to irregularly shaped lesions, which appear on the leaves and stems 3 to 5 days after infection . These can appear all over the plant, especially if the weather is humid. During cool, moist weather, lesions expand rapidly into large, dark brown or black spots that look water-soaked. In humid conditions, the underside of the leaf spot will show a grey or whitish powdery substance, that is primarily spores. You may also see a white velvety coating over the spots and stems, especially when it is damp in the morning. (see excellent photos on the Cornell website). This looks quite different from Early Blight (*Alternaria solani*) – in Early Blight the lower leaves start to show yellow spots, then mottling, and then brown circular spots appear with eventually a "bulls-eye" pattern. Early Blight is an annual problem, and leaves die from the bottom up, but it does not kill the plants off rapidly like Late Blight.

Can it be controlled organically?

While conventional growers have an arsenal of fungicides they can use to protect their crops, organic growers have very few. Once plants have been infected, it is very difficult to stop this disease. Copper sprays are effective as protective materials, but they do not work to kill the fungus already in the plant. If the infection is not too bad, and you spray right away, and then monitor daily to prune any affected leaves, AND the sun shines, you may be able to limit the damage.

Here is some advice for organic farmers from Dr. McGrath of Cornell and Dr. Steve Johnson, University of Maine about **managing late blight in organic systems**.

1. Check with weather reports and extension service for information about late blight occurrence. Note that during cloudy conditions spores of the late blight pathogen can survive being dispersed in wind currents long distances (miles!) because they are protected from the killing effects of UV radiation. Rain can bring these spores down on to plants far from the affected plants that were their source.

2. Apply fungicides preventatively, using a 5-7 day schedule when conditions are favorable. Copper is effective for protecting a crop, but copper has been found to be ineffective when used as the sole practice for controlling late blight once it has started to develop. Thorough spray coverage is critical since copper is a contact fungicide. Use a pressurized sprayer if possible, and apply to undersides as well as top of leaves.

3. If symptoms of late blight are found in isolated areas in a planting, it may be possible to save the crop. Success depends on how early in disease development symptoms are found, how many infections are present that have not yet resulted in symptoms (spore germination to symptom takes about 1 week), how quickly and thoroughly diseased tissue will be removed, environmental conditions, proximity to other gardens or farms where late blight is developing, and what management steps will be taken. Immediately remove affected plant tissue. It is best to do this in the middle of a sunny day after the leaves have dried when there will be fewer spores and those dislodged in the process will likely be exposed to UV radiation. Put affected tissue in garbage bags, dig a hole and bury it, or put it in a pile and cover with a tarp. Heat that develops from sunlight hitting the tarp will quicken death of plant tissue and the pathogen. Inspect plants daily thereafter for a week in order to find any additional affected plants that develop symptoms, and then return to inspecting at least once a week. Apply copper fungicides every 5-7 days as indicated on the label until final harvest or the crop is destroyed. It is not possible to control late blight by solely relying on removing affected tissue. Even when rain is not occurring, dew over night can provide a sufficient leaf wetness period for infection. Especially when conditions are favorable it may not be possible to control late blight with copper. Monitor disease development and be prepared to destroy fields if it gets out of hand.

4. Work in affected fields last. Clean equipment between fields.

5. When late blight starts to become severe the foliage should be destroyed to eliminate the planting being a source of spores for other tomato or potato plantings on the farm or other farms. Propane flamers are a good way to quickly kill foliage, but are not suitable where tomatoes are grown with straw or plastic mulch or trellised. This is an obligate pathogen that needs living host tissue to survive. To initiate plant death with trellised tomatoes, go through the planting and cut all main stems at the base, then come back through and cut stems further up in the canopy. Disturb foliage as little as possible to minimize the amount of spores dislodged. It is best to do this work in the middle of a sunny, preferably calm day after any moisture on leaves has dried to minimize the quantity of spores and also their likelihood of survival in the process. Next remove trellising line and stakes, then flail chop. Bagging affected tissue or burying is recommended where feasible with small plantings.

   The late blight pathogen is not thought to be able to survive in plant debris; therefore it is not necessary to physically remove affected plant tissue from a field.

   The late blight pathogen cannot survive on stakes, therefore it is not necessary to trash or even disinfect the stakes to manage this disease. Stakes should be disinfected however, especially if bacterial diseases also developed in the planting.

9. Fruit from an affected field can develop symptoms after harvest and thus should be inspected just before marketing.

10. **For potatoes**: monitor and spray as above. When late blight starts to become severe the foliage should be destroyed to protect the tubers from infection and to eliminate the planting being a source of spores for other tomato or potato plantings on the farm or other farms. It is especially important to vine kill when late blight is developing on stems because from this location spores can more easily be washed down to tubers than from leaves. Destroy foliage in the middle of a sunny, preferably calm day after the leaves have dried to minimize the quantity of spores and also their likelihood of survival in the process. Propane flamers are a good way to quickly kill foliage. Flail chopping is another option.

    Applying copper fungicide to protect stems that remain from late blight is not recommended because conditions are much less likely to be favorable for infection once all the foliage is removed. Do not hill potatoes that remain in the field in an effort to protect the tubers because the pathogen can be easily spread on equipment, and the root pruning that will occur may stop plant growth for several days.

11. Harvest tubers after foliage has died but before significant rainfall is predicted. Waiting two weeks to harvest after vine kill is considered to provide an adequate time for spores to die. Rain can wash spores down to tubers. And tubers should not be harvested when wet. Infection is more likely to occur when soil temperatures are cool (below 54F). Avoid bruising and skinning while harvesting. Tubers from an affected field should not be marketed until checked for blight. Prompt marketing is recommended. If stored, cool down quickly and provide good ventilation in storage.

12. **Destroy any affected tubers. This is how the pathogen survives over winter**. Late blight cannot live on dead plant tissue, it only survives here on potato tubers (not in tomato plants or debris). It is important to destroy all cull potatoes left in the field. Recommended methods include chopping, burial, burning, spreading on fields where they will freeze completely over winter, or feeding to livestock.

13. Promptly destroy any volunteer potatoes in subsequent years. These can be a source of the late blight pathogen

Current OMRI approved copper products:
Champ WG by Nufarm
COC WP by Albaugh
Nu Cop 50WP by Albaugh
Concern Copper Soap Fungicide - by Woodstream

Cueva Fungicide Concentrate by Neudorff
Lilly Miller Cueva Copper Soap Ready to Use by Lilly Miller
Nordox 75 WG by Nordox

PCO has also approved:
Soap-Shield Flowable Liquid Copper Fungicide by Gardens Alive
Liquid Copper Fungicide Concentrate by Bonide

It is important to follow all label instructions when applying copper products. There is a 24 hour restricted entry interval and other worker protection requirements when applied to crops intended for market.

Other organic approved biological products that have labels for late blight include Sporatec (plant essential oils including rosemary, clove and thyme oil), Serenade, Sonata (both are *Bacillus subtilis* products), and Oxidate (hydrogen peroxide, peracetic acid). There is little data about effectiveness of any of these products however.

CROP LOSS:
If you anticipate a crop loss, please contact a representative from your County Emergency Board to file a loss report. A representative would be the County Agricultural Agent or a representative from the local Farm Service Agency (FSA) or Natural Resource Conservation Service (NRCS). All growers should contact their crop insurance agent, if insured. This is important because the county emergency representatives will document the loss, submit it to the State Emergency Board, who will make a recommendation to Sec. Wolff regarding requesting a disaster designation from the USDA via the Governor's Office. This may make funds available for compensation.

For more information:
Cornell website: with excellent photos and links to more info, including a advice on what to do with initial outbreaks:
http://www.hort.cornell.edu/department/Facilities/lihrec/vegpath/photos/lateblight_tomato.htm

Penn State Dept. of Plant Pathology website: includes latest updates on disease outbreaks in PA.
http://www.ppath.cas.psu.edu/

Late Blight: Frequently Asked Questions

By Gardeners, Growers, & Consumers

Updated 8/26/2009

Prepared by Margaret Tuttle McGrath, Department of Plant Pathology and Plant-Microbe Biology, Cornell University, Long Island Horticultural Research and Extension Center, Riverhead, NY

Note: More answers will be added as new questions are asked.

When you observe the devastation of late blight in your garden or crop, be thankful that you, unlike the Irish people in the mid 1800s, are not dependent on those plants for your sustenance and try to imagine what it was like for those people to watch their plants die with no knowledge of what was happening and no tools to manage it even if they did know.

1. What is late blight?

Late blight is a very destructive and very infectious disease that affects tomato and potato (not sweet potato). It is the same disease that lead to the Irish Potato Famine in the 1840s. It is caused by the fungal-like pathogen, *Phytophthora infestans*. Late blight occurs regularly but very sporadically in the Midwest and Northeastern U.S.A. It often develops in major potato production areas because potato tubers have been the main source of initial inoculum for disease development in these regions. The pathogen has not been able to survive outside of living plant tissue. Late blight occurs very sporadically due to aggressive management programs on commercial farms, which limit the quantity of wind-dispersible spores produced by the pathogen on leaves, the fact wind doesn't generally move southward from major potato production areas in the northern part of the region toward areas where there is more tomato production and gardens, and the pathogen strain that has been occurring in potato is not as aggressive on tomato.

2. Are all tomatoes and potatoes in the northeastern US doomed to get late blight this season because of the wet weather?

No. In addition to requiring that there be favorable conditions (cloudy, rainy, and not too hot) and a susceptible plant (tomato, potato, and some related weeds), late blight cannot develop unless the pathogen that causes this disease is also present.

This disease normally occurs sporadically in the Northeast, and rarely in many parts, because the pathogen is usually not present. For late blight to develop in a particular garden or field the pathogen has to be there, which it accomplishes by being brought in on infested potato seed tuber pieces or infected tomato transplants or blown in as spores (which function like seeds for pathogens) from affected plants in another location.

Some plants may ‘escape’ late blight if the pathogen does not get on them. However, the chances of this happening this year are very low based on the fact occurrence of late blight is very widespread very early in the summer growing season.

3. What other diseases could be confused for late blight?

There are several diseases that can cause dark spots on leaves and stems of tomato and potato plants. Most of these are smaller than those due to late blight. Botrytis gray mold is the most similar. It is always best to have plant tissue with suspected disease symptoms examined in a plant diagnostic clinic.

4. If I grew my own tomato plants from seed do I need to worry about late blight?

Yes. While the pathogen does not have a means to get into seed and it cannot survive on seed, this year there will be a lot of wind-dispersed spores with so many occurrences of late blight widely distributed in the eastern U.S. this early in the season. These spores can be moved long distances.

5. Are tomatoes grown in greenhouses or high tunnels protected from late blight?

No. In fact at some farms the tomatoes in high tunnels have been more severely affected than those in the field! The pathogen that causes late blight needs only high humidity to infect. Thus it is similar to the pathogens that cause gray mold and leaf mold, which commonly occur in tomatoes grown in these protected environments where humidity typically is higher than outdoors. Leaves need to be wet for other pathogens to infect; additionally, several need splashing water for dispersal, thus Septoria leaf spot, early blight and bacterial speck/spot are uncommon in protected tomatoes. The sides of high tunnels are rolled up on hot days, thus these structures do not provide a barrier that prevents spores of the late blight pathogen from getting to the plants inside. Greenhouses provide better protection, but most have vents and thus are not completely sealed.

6. Can late blight be suppressed in greenhouses and high tunnels by maintaining high temperatures?

High temperature likely will slow disease development since cool temperatures are favorable for most strains of this pathogen. However, excessive heat can be detrimental to tomatoes. Temperature should be kept below 90 F. Pollen can be killed when above 90 F, which affects pollination resulting in small or puffy (flat sided) fruit. Additionally lycopene is destroyed resulting in fruit with poor red color, streaking, green shoulders, etc. Internode length will increase. Plants will be stressed. And they are more likely to wilt leading to problems like blossom end rot.

7. Can plants be saved in a garden once late blight starts to develop?

This depends on amount of symptoms seen, type of symptoms, how early in disease development symptoms were found, environmental conditions, proximity to other gardens or farms where late blight is developing, and management steps being taken.

It is more likely possible to save plants in a garden if when the first symptoms are found:

1. There are very few.
2. They are on the leaves and not stems.
3. The garden has been inspected very thoroughly on a frequent basis (preferably daily) and thus the symptoms are discovered shortly after they formed.
4. Conditions are expected to be hot with no rain or lengthy dew for a prolonged period.
5. There are no nearby places with late blight that could be a source for more spores.
6. Further development of late blight will be slowed by regularly removing affected tissue (daily cut off and bag, preferably during the day when plants are dry and there will be sunshine for several hours afterwards) and applying fungicides (minimum of weekly).

Additionally, success is more likely if fungicides were applied before symptoms were seen (thus there will be fewer initial symptoms) and spray coverage is maximized by using a pressurized pesticide sprayer to plants that are trellised. Removing extra branches will also help.

Realize that even with an ideal situation (all above conditions met) there is no guarantee that success will be achieved. Late blight is a very destructive and difficult to manage disease. Impact can be great considering that tomato fruit and potato tubers that become infected can quickly rot.

Plants can be killed quickly when late blight is not managed. A spot (lesion) can form within 4 days of when a spore lands on a plant (even faster, less than 3 days, with one strain of this pathogen) and a day later be producing spores that can be dispersed by the wind to healthy plant tissue resulting in more spots within a few days. Lesions that develop on stems are especially destructive.

Late blight needs to be aggressively managed not only to try to save plants in the garden but also to avoid having the affected plants serve as a source of inoculum (wind-dispersed spores) for other gardens and farms. Promptly remove affected plant tissue on a regular basis.

Realize that when symptoms are first seen, all points of infection likely are not yet visible. There is a 'latent' period of a few days between infection and when symptoms are visible. As a result, initially fungicides may appear to be not working when applications are started after symptoms are found. No fungicide can cure tissue that is already affected, and this tissue will produce more inoculum. Thus it can be impossible to stop late blight when there are a lot of symptoms.

Also rogue out any volunteer tomato plants growing from seed of previous year's tomatoes and susceptible weeds like bittersweet nightshade. Given the amount of effort to try to save a garden once late blight starts to develop, especially when it is early in the season, and the chance the crop will be destroyed despite the effort, especially if fungicides are not applied frequently, the best option when late blight occurs might be to replace the plants with something like spinach or lettuce that grows quickly.

8. Can plants be saved in a farm planting once late blight starts to develop?

Yes. Growers are able to effectively control late blight, especially potato growers with experience from being in an area when this disease occurs regularly. It is easier to manage late blight on a farm than in a garden because of the fungicides that can be used. Growers using conventional fungicides can use products able to move within the leaf that the spray lands on. Some fungicides can move into stems and new growth. None of these mobile fungicides are approved for organic production.

Growers also have sprayers that can achieve better coverage of plant tissue than hand sprayers used by gardeners. Thus growers can be more successful than gardeners even when they use the same fungicides. As with a garden, success is affected by whether or not fungicides were applied before symptoms were seen and how severely the crop is initially affected if fungicides were not applied.

Typically growers begin applying a broad-spectrum, contact* fungicide when conditions are favorable for late blight, inspect their crops regularly, and when symptoms are found start applying fungicides with specific activity for late blight. They also manage the usual initial source of the pathogen: affected tubers from the previous year or used as seed. See also answer to previous question.

9. Do I really need to apply fungicides preventively to control late blight?

If fungicides are not applied preventively, there is a risk that when this disease begins to develop, there will be too many symptoms to achieve control.

Fungicides cannot ‘cure’ a spot that has already developed (disease control in plants is very different from humans). This tissue will soon die, but before it does the pathogen will produce hundreds of spores. The more spores, the greater the odds some will be dispersed to plant tissue that has not received fungicide.

It is difficult to achieve complete coverage of plant tissue with fungicide, especially when a contact* fungicide is used, even with the best farm sprayer. The underside of leaves is an especially difficult area to reach (the pathogen can infect through either surface), which is why growers who can use fungicides able to move through leaves are better able to control late blight.

Only contact* fungicides are available to gardeners. Note that there are precautions that need to be taken when applying fungicides. Read the label to determine what protective equipment is required (e.g. water-proof or chemical-proof gloves, shoes plus socks, long pants, long-sleeved shirt, goggles, respirator).

10. Do I really need to apply fungicides frequently to control late blight?

Yes. Fungicides applied on a plant, even those that get inside of the plant, disappear over time due to being broken down biologically or by sunlight and/or being washed off by rain or irrigation. After about 7 days the concentration (dose) of many fungicides can be too low to be adequately effective.

11. Do I need to be concerned about bees when I spray fungicides?

Chlorothalonil and copper fungicides have been rated ‘relatively nontoxic’ to bees. Insecticides are a much greater concern generally than fungicides.

Additionally tomato and potato are pollinated mostly by wind and not commonly visited by bees compared to some other crops. To avoid exposing bees to pesticides, apply them during late afternoon or early evening when bees are less active. Applying when there is no wind minimizes the chance of drift to other plants that bees visit more commonly.

12. Can late blight be exacerbated by handling plants, such as during pruning and trellising tomatoes?

Possibly, but the quantity of spores dislodged by the plant movement that occurs during these activities might not be more than what would occur naturally by wind. Human impact on pathogen spread is expected to be much less with late blight than with a pathogen like the one causing bacterial canker, which is in the sap of plants, can be picked up on hands and any tools, can be deposited while handling another plant, and can enter a plant through wounds that occur during pruning and trellising. Better spray coverage can be achieved when plants are pruned and trellised rather than left to grow on the ground.

13. Should potatoes be harvested early?

Maybe. When to dig depends on late blight severity, management practices, risk of this infection to other plantings, and environmental conditions. Early harvest should be considered if there are other plantings of potato or tomato without late blight in the general vicinity, and fungicides are not being applied for late blight to the affected potato planting. Potato tubers are susceptible. They are more likely to become infected when late blight symptoms are on stems, rather than just on leaves, because rain is more likely to wash spores from stems down to tubers. The pathogen is better able to infect when soil is cool (below 54 F is most favorable) and wet.

Harvesting as a preventive measure is not usually warranted; however, this might be a worthwhile consideration where the crop is not being inspected for symptoms, there is not an action plan that can be immediately implemented when late blight develops, and there is a concern that any affected tubers will not be properly managed. An affected tuber left in the ground or tossed on a compost pile could grow next year into an affected plant that serves as inoculum to start another epidemic!

Tubers are routinely left in the ground for about 2 weeks after the plants die (or the vines are killed mechanically or chemically) in order for the skins to set. During this time tubers already affected by blight might rot. It is also best to harvest when soil is dry, before a significant rainfall, and after foliage affected by late blight has died to avoid exposing tubers to those spores. Avoid bruising and skinning while harvesting which will make tubers more susceptible to infection. Harvest thoroughly: infected tubers are the usual main source of the late blight pathogen.

14. What should be done with affected plants when late blight cannot be controlled?

Affected plants should be promptly destroyed to minimize the potential for them being a source of spores for other plantings. Growers can kill them with a very fast-acting herbicide like diquat (glyphosate is too slow). Burning with a propane flamer is another option. Or plants can be pulled out and put in a garbage bag (suitable for small plantings) or either piled and covered with a tarp or buried deeply. The best time to pull plants is a sunny day because UV radiation can kill spores dislodged in the process, but don’t wait several days for this to occur. Leave the bagged plants for a few days in a sunny spot so heat will build up inside and kill the plants before they are put out with trash. Heating will also occur under a tarp. The late blight pathogen cannot survive in dead plant tissue, unless oospores are formed. Oospores are unlikely to be present because formation requires interaction between individuals of the pathogen (aka isolates) of opposite mating type (equivalent of male and female). All isolates tested so far have been the same mating type. The pathogen can survive in potato tubers because these are living; therefore, destroying affected tubers is extremely important.

15. Can plants with late blight be disposed of by composting?

Yes if done correctly. Considering the potential impact of not composting correctly, especially with potato plants that have tubers, it is prudent for home gardeners to bag and trash the plants (see previous question). Plants should not just be dumped on a compost pile. Either cover with a tarp or bury them so that there is not an opportunity for spore production and dispersal by wind to another planting or farm before the plant tissue completely dies. Based on results from a laboratory study, temperatures above 115 F, which commonly occur in proper compost piles, are adequate to kill even the pathogen's most durable type of spore (oospore) within 2 hours. Oospores are unlikely to be present because formation requires interaction between individuals of the pathogen (aka isolates) of opposite mating type (equivalent of male and female). All isolates tested so far have been the same mating type.

Guidelines have been developed on composting cull potato tubers for commercial operations: http://www.umaine.edu/umext/potatoprogram/Fact%20Sheets/Composting%20Cull%20Potatoes.pdf.

16. Are there any health issues from breathing spores of the late blight pathogen such as could happen when pulling up affected plants?

None known. There is one scientist who has been studying late blight for many years and is a good test case for health issues since he is allergic (asthmatic) by inhalation to flour, as well as components of livestock feed and hay. He has not experienced any health issues from inhaling large quantities of spores over more than 30 years (1973 to 2007), nor has anyone who has worked with him during all those years. No published scientific study has been conducted on this specific issue, however. Anyone concerned about breathing spores could wear a dust mask to reduce exposure.

17. Could the late blight pathogen survive on tomato cages and stakes between seasons?

No. Therefore it is not necessary to discard or even disinfect the cages or stakes to manage this disease. Stakes and cages should be disinfected however, especially if bacterial diseases also developed in the planting. Disinfectants include: quaternary ammonium chloride salts (e.g. Green-Shield), sodium hypoclorite (Clorox or other household chlorine bleach; these are 5.25%; use at

0.5% = 1 part bleach + 9 parts water), and hydrogen dioxide (e.g. OxiDate). Clean off soil and organic matter first because this inactivates disinfectants and can protect pathogens that are inside. This is especially important when using bleach. Soak at least 10 minutes. Disinfectant solution can be reused until it becomes dirty or ineffective (replace Green-Shield after 24 hours; half-life for bleach is only 2 hours).

18. Could the late blight pathogen survive in soil between seasons?

Unlikely except in affected potato tubers. This is an obligate pathogen that is thought to only be able to survive in living plant tissue in the northeastern U.S. It can produce a specialized structure (oospore) that would enable it to survive without living plant tissue, but this requires that the pathogen reproduce sexually which it is not thought to be able to do in the northeastern U.S. So far only one "mating type" has been found in the Northeast. This is the term used for the pathogen's equivalent of male/female. Thus the pathogen has only been able to reproduce asexually. The characteristic white growth that develops on late blight affected tissue contains many asexually-produced spores. Both mating types have been found in Florida.

19. Could the late blight pathogen survive between seasons on perennial weeds that it is able to infect (e.g. bittersweet nightshade and hairy nightshade)?

No. This is an obligate pathogen that needs living plant tissue to survive. It only infects foliar tissue of weeds. Since the pathogen cannot infect roots, it cannot survive on weeds in areas where foliage is killed by cold temperatures. In the Northeast, potato tuber is the only plant tissue it is able to survive in.

20. Could the late blight pathogen survive in or on tomato seed?

No. Fortunately this pathogen is not able to get inside seed and it does not produce a type of spore that is able to survive the dry conditions on the outside of a seed. Thus there is no concern that late blight will develop as a result of growing plants next year from seed that were in tomato fruit affected by late blight. There are other pathogens that can be in or on seed, however, thus there are other reasons to use seed from healthy plants.

21. Could tomatoes and potatoes become affected by blight after they are harvested?

Yes. Tomatoes and potatoes can be infected but appear healthy. Additionally, the pathogen can spread in a moist environment from affected to healthy tomatoes and potatoes. Produce from affected plants should be checked regularly and not kept long to avoid losses. Consumers should be aware that the shelf life may be shortened.

22. Could marketing affected tomatoes and potatoes be a means of spreading the late blight pathogen?

Yes, especially if the affected produce is discarded on a compost or cull pile near tomato or potato plants. This is primarily a concern with potatoes. Consumers should be instructed to put affected tissue into the trash rather than the compost.

23. Are the unaffected parts of blighted tomatoes and potatoes safe to eat?

Yes the unaffected parts probably are safe to eat. Tomato sections without blight symptoms likely do not pose a health risk to the consumer. They may not look appetizing and will have an off flavor. However, no published scientific study on this specific issue was found to confirm this conclusion. On the other hand, there also have been no reports of a health problem possibly associated with consuming tomatoes or potatoes affected by late blight to warrant such a study. One study documented no association with birth defects. Late blight has been affecting tomato and potato plants for a long time, and there have been years when several crops were affected due to lack of adequately effective control measures. Thus there might have been enough consumption over the years for any problem to be revealed. Additionally, there is a story that someone ate blighted potatoes many years ago to dispel the myth that blight was associated with typhoid.

The conclusion that unaffected tissue is safe to consume if diseased sections are adequately removed is based on several points. This pathogen does not produce a toxin that can make people sick, as a few plant pathogens can do. Plant pathogens cannot infect people. No food safety issues have been found with other diseases that affect tomato fruit or potato tubers. Late blight appears to be like other more common diseases, e.g. anthracnose on tomato fruit and pink rot of potato (which incidentally is caused by *Phytophthora erythroseptica*, a pathogen related to that causing late blight), in that these do not appear to affect plant tissue beyond the area of infection. Many home gardeners likely often cut off diseased tissue rather than throw out the entire fruit or tuber having found the healthy appearing part of these to taste fine. To date, this practice has not been associated with any human health issues. Diseases like late blight and anthracnose are not considered a health concern for commercial tomato processing. Fruit are sorted to remove affected ones, but this is because of the impact on fruit quality. For home canning, only disease-free, preferably vine-ripened, firm tomatoes are recommended in the USDA Complete Guide to Home Canning because fungal pathogens may raise tissue pH (which has been supported by recent studies) and thereby allow growth of potentially harmful microorganisms, such as Salmonella.

Deterioration can occur quickly after infection; therefore, affected tomatoes and potatoes should be salvaged and consumed right away.

24. Is it safe to eat tomato fruit with visible fungicide residue?

Yes, but advisable to wash fruit to reduce exposure. Fungicides are the main tool for controlling late blight. Regardless of whether pesticides have been applied, all fresh produce should be washed before consuming to remove dust and other contaminants, which could include organisms that cause food-borne illness.

It is not uncommon for a residue to be visible. Many pesticide spray solutions are cloudy. Many are formulated with ingredients that help improve product efficacy, including 'stickers' that help keep the pesticide on plant tissue to extend the period of time that it is there to protect the plant from infection by pathogens. Residue present at the time of purchase means the fruit has had protection through the marketing process when it also could have been exposed to the late blight pathogen in addition to field exposure.

Instructions on pesticide labels are developed to achieve control without leaving a toxic level of crop residue. Labels are legal documents, thus growers and other pesticide applicators must follow these instructions. Pesticide registration decisions in the U.S. are done by the EPA (Environmental Protection Agency). Products must be reviewed by EPA before they can be sold. New products are evaluated and old ones are re-evaluated every 15 years by EPA to ensure there will be no 'unreasonable adverse effects on humans, the environment and non-target species'. A major component of the registration process for pesticides is determining human toxicity and the amount of residue present when a product is applied the maximum amount according to the label (highest rate and maximum number of applications). Product efficacy is not a component of the decision.

25. Why is there residue on organic tomatoes? Is it safe?

Growers producing organically also need to protect their crops from late blight this year for which there are fungicides that have been approved for organic production. Yes tomatoes with residue are safe. See also previous question.

Copper probably is the main fungicide being used for managing late blight organically. The residue is often bluish. This reportedly is one of the easiest fungicide residues to remove from produce. Additionally, it is only on the fruit surface since it is strictly a contact fungicide and cannot get inside of the fruit as can occur with some conventional fungicides. Copper fungicides are now undergoing the routine re-registration process with EPA that occurs every 15 years for all pesticides. There are no human toxicity concerns associated with produce treated with copper fungicides and, while there is a defined concentration range for these fungicides that can be used for an application, there are no restrictions on the total amount that can be applied to a crop over a season.

Copper is a natural element that is an essential trace mineral for humans and all other organisms that need oxygen (aka aerobic). Many vital human bodily functions are dependent upon copper. It is needed for development and performance of several human systems (nervous, cardiovascular, immune, and reproductive systems plus skin and bone). It plays a role in protecting against cancer and heart disease. The National Research Council recommends 1.5 to 3 mg of copper per day for adults to avoid copper deficiency; an RDA has not been established. There are few toxic effects from copper. Daily intake of copper exceeding 20 milligrams can cause vomiting. However, individuals with Wilson's disease, an inherited genetic disorder, need to watch their copper consumption because their bodies are unable to properly excrete copper and it can accumulate to levels that lead to liver disease and mental retardation.

26. What crops can be grown immediately after tomatoes or potatoes are lost to late blight?

The only crops you wouldn't want to plant are tomatoes or potatoes, which typically it will be too late for anyway. Since the pathogen has a limited host range and cannot survive as a saprophyte on dead plant tissue, it does not matter what is planted immediately after crops lost to late blight. Crops most likely to be successful planted in mid to late summer are those that quickly produce something edible and grow well in cool, fall weather. Spinach, lettuce and other leafy greens are good options. Where harvesting of individual leaves can be done, these crops can begin yielding produce quite quickly. Peas also do well under cool temperatures, but might not produce many pods before a killing frost.

27. Are there resistant varieties?

There are some potato varieties described as having some resistance. These include Elba, Kennebec, Allegany, Sebago, Rosa, Defender, Jacqueline Lee, and Ozette. Elba is considered the most resistant. There are some tomato varieties in the final stages of development expected to be available perhaps as soon as 2010. Mountain Magic is one variety with resistance to early blight and Septoria leaf spot (diseases that occur commonly) as well as late blight.

28. What is the most important thing gardeners and growers can do to prevent another late blight epidemic next year?

Destroy potato tubers that appear to be affected by late blight and also volunteer potatoes that grow next year. The late blight pathogen cannot survive in infested plant debris but it can survive in tubers because only the latter is living tissue. Infected tubers can be destroyed by proper composting, deep burial, or freezing. Freezing can be accomplished by spreading tubers on the soil surface in an area where it get sufficiently cold over winter. Tubers in a pile can be protected from freezing.

29. What has been the impact of the late blight epidemic in 2009?

Major impact has been on home gardeners since they don't know this disease and most don't apply fungicides. Late blight occurs very sporadically and is generally confined to the major potato production areas. Some commercial crops also have been destroyed by late blight and others sustained a lot of loss, especially those being produced organically. This was partly due to outbreaks where growers lack experience with the disease. But many crops, organic as well as conventional, receiving a good fungicide program have been saved. For these growers the impact is increased costs for disease scouting and fungicides plus application expenses, in particular for products that target the late blight pathogen which they don't usually need, as well as a lot of stress. Area impacted by this epidemic began with the Mid-Atlantic and Northeastern states. By mid-summer late blight also had been reported in OH, IN, IL, MI, and WI. Prior to this there had been reports of late blight in FL, GA, SC, and NC.

* Contact fungicides remain on the surface of the plant tissue where they are deposited whereas translaminar fungicides can move in and through a leaf. A very few fungicides are systemic and can move in the plant to stems and new growth. In contrast, most human drugs are put inside the body and are able to move to where they are needed and they have a curative effect. Plant medicine is very different from human medicine.

Performance of Tomatoes (all *Solanum lycopersicum* unless noted) (**H**ybrids, **O**pen **P**ollinated and **He**irlooms) for Late Blight (LB) and Early Blight (EB). – T. A. Zitter, Department of Plant Pathology Cornell University, March 2010.

Tomato Cultivar	**Specifics and Seed source**	**Ref. of LB/EB Rx (year)**	**Genetic resistance**	**Comments**
Fresh Market Reds				
Legend OP	Det., rnd red, 14-16oz; **Territorial** (9)	Not tested locally; (dev. Dr. Baggett, OSU) (1)	Reportedly tolerant for US8 and US11; *Ph2* only; EB res.	*Ph2* resistance will not provided resistance for current isolates of LB.
New Yorker OP	Det., rnd red, 4-6 oz, early season; **Online**	Not tested locally; (dev. NYSAES, Geneva, NY)	Resistance *Ph1* gene	*Ph1* gene will not provide resistance for current races of LB.
West Virginia 63 OP	Indet., rnd red, 6.5oz;**Online**	Not tested locally; (dev. Dr Gallegly, WVU) (5)	Reported as *Ph2* gene	*Ph2* gene will not provide resistance for current races of LB.
JTO-99197 F1	Det., large globe shape; **Johnny's**	Resistant for EB (8)		Suited for vine-ripe production.
Heirlooms				
Aunt Ginny's Purple	Indet., pur/blk, beefsteak, 16oz; **Online**	Good resistance US17 (2002, 2006) (4)	None reported	Potato-leaf plant.
Aunt Ruby's German Green	Indet., gr. beefsteak, 8-18oz; **Online**	Moderate resistant US17 (2002, 2006) (4)	None reported	
Big Rainbow	Indet., bi-colored beefsteak >16oz; **Online**	Good observations US22 (2009) (10)	None reported	
Black Krim	Indet., maroon, beefsteak ,10-12oz; **Online**	Mod. res. US17 (2002, 2006); mixed performance US22 (2009), (4,10)	None reported	
Black Plum	Indet., mahogany plum, 2 in. elongated; **Online**	Highly resistance US17 (2002, 2006) (4)	None reported	
Brandywine	Indet., pink fruit, oblate 1-2 lb.; **Johnny's**; **Online**,	Moderate resistance US17 (2002, 2006) (4)	None reported	Prolific potato-leaf plant.
Pruden's Purple	Indet., dk. pink, >16oz; **Johnny's**	Moderate resistance US17 (7)	None reported	Medium potato-leaf plant.
Slava	Indet., red, 2 in.; **Online**	Some resistance reported US17 (3)	None reported	Potato leaf variety, Eastern European
Stupice	Indet., red, 2-3 in.; **Territorial** (9)	Some resistance reported US17 (3)	None reported	Potato leaf variety, Eastern European.
Tigerella (**AKA Mr. Stripey**)	Indet, bi-color, 4-6oz; **Online**	Observed good tolerance US22, (2009) (10)	None reported	Productive small round fruits with reddish-orange skin and stripes.

Saladette (large cherry), Plum				
Juliet, Plum cluster F1	Indet., 1 ½ -2 oz; **Johnny's**	Intermediate resistance for LB (US17) and EB (2009) (3,7,8)	South Asia, *Ph* gene(s) likely	Larger sister variety of 'Santa'.
Mountain Magic F1, **Large Cherry**	Indet. 2oz size; **Bejo** (2), **Johnny's**	Excellent with exposure to US22 (2009); multiple isolate resistance US11, US17 (6,10)	Heterozygous for *Ph2* and *Ph3*; homozygous tolerant for EB	**Limited or not available in 2010**; (dev. Dr Gardner, NCSU).
Plum Regal F1, **Plum**	Det.; **Bejo** (2)	Excellent with exposure to US22 (2009); multiple isolate resistance US11, US17 (6,10)	Homozygous resistant *Ph3*; Homozygous tolerant for EB	**Limited or not available in 2010**; (dev. Dr Gardner, NCSU).
Small-fruited Grape, Cherry, Pear (assorted colors)				
Red Currant, **OP**	Indet., 3/8-inch, sweet (but slightly tart); **Online**	Good resistance US 17 (2002, 2006) (4,7)	None reported	Vigorous growth and many fruit.
Red Pearl, **Grape**	Indet., 1oz; in clusters **Johnny's**	Intermediate resistance for LB US22 (2009) (8)	None reported	Compare to 'Red Grape' F1, but larger fruit.
Matt's Wild Cherry Sm. Red Cherry He, *S. lycopersicum* var. *cerasiforme*	Indet., cherry, ½ in. borne in clusters; **Johnny's, Online**	Excellent resistance US17 (2002, 2006); observed res. US22 (2009) (4,7,10)	None reported	Rampant vines; Probably *Ph3*; origin is Hidalgo state in eastern Mexico.
Yellow Currant, *S. pimpinellifolium*	Indet., very small, 1/2-inch almost translucent yellow cherry; **Online**	Excellent tolerance US17(2002, 2006) (4,7)	None reported	Regular leaf; fruit borne in cluster of 6-8 tomatoes.
Yellow Pear, **OP, He**	Indet., cluster; ¾ - 1 oz; **Johnny's; Online**	Excellent tolerance US17 (2002, 2006) (4)	None reported	Tall and vigorous vine with many fruit.

1. Baggett, J. R. 2001. http://extension.oregonstate.edu/news/story.php?S_No=312&storyType=garden

2. Bejo Seed 2010. http://www.bejoseeds.com/gba/upload/pdf/347/Bejo%20Tomatoes%20Eastern%20U.S.%202009.pdf

3. Dillon, M. 2005. Public breeding for organic agriculture. Screening for horizontal resistance to late blight in tomato. http://ofrf.org/funded/reports/dillon_04s20.pdf

4. Fry, W. E. 2002, 2006. From trials conducted by Dr. Hilary Mayton formerly with Dr. W. Fry's Lab Group (http://www.plantpath.cornell.edu/Fry/LB_Tools.html#heirloom)

5. Gallegly, M. E. 1960. Resistance to the late blight fungus in tomato. Proc. Plant Science Seminar. Campbell Soup Co., Camden, NJ.

6. Gardner, R. G. 2008. http://www.ces.ncsu.edu/fletcher/programs/tomato/releases/release-notices/release-Mountain-Magic.pdf; http://www.ces.ncsu.edu/fletcher/programs/tomato/releases/release-notices/release-Plum-Regal.pdf

7. Inglis, D., Gundersen, B., and Derie, M. 2001. Evaluation of tomato germplasm for resistance to late blight, 2000. Biological and Cultural Tests for Control of Plant Diseases 16:PT77. http://ipcm.wisc.edu/WCMNews/tabid/53/EntryId/875/Managing-Late-Blight-in-Tomatoes.aspx

8. Johnny's Selected Seeds. 2010. http://www.johnnyseeds.com/c-1-vegetables.aspx; personal communication.

9. Territorial Seed Company. 2010. http://www.territorialseed.com/prod_detail_list/vegetable_seed

10. Zitter, T. A. 2009. Personal observations and correspondence.

Branch Creek Farm, Perkasie PA — Insect Management

Mark and Judy Dornstreich have been farming for over 30 years in beautiful Bucks County, PA. They produce baby greens, specialty vegetables and edible flowers year round in 3 greenhouses. Come summer they shift their attention out to the field where they grow unique vegetable varieties on about 5 acres. They provide Philadelphia and New York City restaurants with only the highest quality, mouth-watering produce.

Greenhouses

There are several pests that have made quite a comfortable home in the greenhouses on Branch Creek. Slugs, sowbugs and aphids are the biggest problems. The slugs hide in the dark, damp crevices between the wooden beds. They are an issue because they occasional get into the beds so you have to be careful when harvesting the baby greens because they can easily be missed… and end up in someone's salad mix.

The same thing goes for the sowbugs. The bed frames are made of untreated wood and they are relatively old at this point, so they are beginning to break down. The sowbugs like the moist, dark environment of the decaying beds. They occasionally will take a bite out of the young plants but, like the slugs, they are more of a nuisance.

Aphids cause the most damage in the greenhouses. They vector diseases, cause the foliage to curl and may also cause plant death. They are mostly a problem on the baby vegetables because those remain in the beds longer than the baby greens. Also, it takes more time to harvest the baby vegetables because they have to be thoroughly washed before going to the customer. When a bed with aphids is found it is promptly removed from the house.

Control Measures

"We control insects in the way we grow the baby greens and vegetables" begins Mark. "The greens are maybe 10 days old when we harvest them. So we're constantly interrupting the pest's life cycle. Ten days isn't enough time for them to go through all their maturation stages and reproduce. We really only have pest problems on our longer term (1 month) crops."

Pest Pointers from Mark

- Properly identify insects because the majority of them are beneficial.
- Spread out. Pests can move fast and far. Because Mark and Judy only use about 5 for production of the 20 acres they own, they have a unique garden set-up. The individual

"gardens" (a few rows of a singular crop) are spaced anywhere from 200 to 1,000 feet apart. This makes it difficult for insects to jump from one desirable food source to the next.
- Stop growing a crop if you know there it has a particular pest issue. For a long time, Branch Creek Farm dealt with gray aphids on their fall crop of Brussels sprouts. This became such a nuisance that they chose to stop growing Brussels sprouts in the fall altogether.

Greenhouse Set-Up

Doors to the greenhouse are kept shut at all times to prevent insects from entering. Scouting is also part of the routine. Going to and from each greenhouse to do inventory of the week's harvest makes it easy to spot issues or changes in plant health. The floor of the greenhouse is covered with stone to prevent weeds from coming up. But, in the areas where the stone is thinly layered weeds do occur. It's important to set time aside during the busy growing season to consistently do some weeding since weeds are the perfect habitat for insects. Moving and cleaning between the beds removes a large number of pests and eggs. This is another frequent sanitation practice at BCF.

Farm Profiles are designed to give new producers ideas and advice from experienced producers. Individual products are mentioned as examples not as an endorsement. Prepared by Aston Ward, Penn State Extension. Photos taken by Aston Ward, courtesy of Branch Creek Farm. Last updated May 2011.

From "Teaching Organic Farming and Gardening"
University of California, Santa Cruz

Appendix: Arthropod Pest Management Field Observations Records Sheet

	Crop:	Crop:	Crop:	Crop:
Date, time				
Stage of crop development				
Is proper cultural care being delivered? Describe				
Genus, species, common name of pests observed				
Number of pests observed				
Amount, type of crop damage observed				
Name, number of beneficial insects				
Evidence of parasitism or predation				
Description of control action threshold for pest				
Management actions taken and date				

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Biology and Management of Aphids in Organic Cucurbit Production Systems

Last Updated: August 10, 2011

eOrganic author: Dr. Mary E. Barbercheck, Penn State University

Summary

This article provides general information on the biology and life cycles, damage from and management of the aphid pests in organic cucurbit crops. Specific information is provided for the most common aphid pests in cucurbits: the green peach aphid (*Myzus persicae*), melon aphid (*Aphis gossypii*), the potato aphid (*Macrosiphum euphorbiae*), and the bean aphid (*Aphis fabae*).

(http://www.ipmimages.org/browse/detail.cfm?imgnum=1317037)

Figure 1. Green peach aphid, Myzus persicae (Sulzer). Figure credit: Scott Bauer, USDA Agricultural Research Service, Bugwood.org (http://www.ipmimages.org/browse/detail.cfm?imgnum=1317037) .

General Information

Aphids (Fig. 1) are small (about 1/8th inch long), soft-bodied, pear-shaped insects with long legs and antennae, commonly found on cultivated plants. Sometimes called plant lice or green bugs, aphids use their long, slender mouthparts to pierce and suck plant fluids from stems, leaves, and other tender plant parts. Aphids can be green, yellow, brown, red, or black. Some secrete a waxy white or gray material that covers their body, giving them a waxy or wooly appearance. Most species have a pair of tube-like structures called cornicles projecting rear-wards from their abdomen. Cornicles distinguish aphids from all other insects.

Adult aphids are usually wingless, but most species also occur in winged forms, especially when populations are high or during spring and fall. Wings allow aphids to disperse to other plants when the quality of the food source deteriorates. Aphids can disperse great distances when carried by wind.

Aphid Biology and Life Cycles

Aphids can produce several generations per year. Most aphid species reproduce asexually (without mating), with adult females giving birth to live immature aphids called nymphs. Nymphs are always wingless. The nymphs molt, shedding their skin multiple times before becoming adults. Aphids can have simple or complex life histories. Some aphid species use only a single species of host plant to complete their life cycle, whereas other species require two species of host plants. Some aphid species mate and produce eggs, which in some cases are laid on an alternate host, usually a perennial plant species.

When conditions are favorable, many species of aphids can develop from nymph to reproducing adult in about one week. Because each adult aphid can produce numerous nymphs in a short period of time, aphid populations can rapidly increase.

Aphids usually feed in dense groups on leaves or stems, although they can sometimes be found singly. Aphid infestations usually start when small numbers of winged aphids fly to or are blown into a field of suitable host plants. They deposit several nymphs on tender plant tissues before flying to a new plant. The nymphs feed on plant sap, molt and increase in size. They mature in 7–10 days and then are capable of producing live young. Aphid numbers build until crowding or plant stress stimulates the production of winged forms. The winged forms fly from the plant to search for new hosts, where the process is repeated.

Damage from many species of aphids is greatest when temperatures are relatively cool (65–80 °F). Aphids tend to first occur along the upwind edge of a field and close to other sources of aphids, so these areas should be monitored closely. Many aphid species prefer the undersides of leaves; be sure to turn leaves over when monitoring.

Damage Caused by Aphids in Cucurbits

Damage from aphids can be direct or indirect. Direct damage to plants occurs from the feeding activity of aphid nymphs and adults. Aphids pierce the plant tissue and extract sap, which results in a variety of symptoms, including decreased growth rates and reduced vigor; mottling, yellowing, browning, or curling of leaves; and wilting, low yields, and plant death. Saliva injected into plants by aphids can cause leaves to pucker, curl, or become distorted. Curled and distorted leaves can protect aphids from natural enemies or applied treatment materials. Aphids feeding on flower buds and fruit can cause malformed flowers or fruit.

Indirect damage can be caused by deposits of honeydew. Honeydew is the sticky, sugary liquid waste produced by aphids as a result of feeding on plant sap. Honeydew can attract other insects, such as ants, that will feed on the honeydew. Ants can aggressively defend aphids (and their honeydew food source) from predators and parasites, and interfere with the control of aphids by natural enemies. Honeydew deposits that accumulate on the plant can also create a growth substrate for sooty molds (Fig. 2). Sooty molds are dark fungi comprised of a complex of several fungal species. Sooty mold growth on leaves and other plant parts blocks light and can reduce photosynthesis.

(http://www.ipmimages.org/browse/detail.cfm?imgnum=1427014)

Figure 2. Sooty mold. Figure credit: Joseph O'Brien, USDA Forest Service, Bugwood.org (http://www.ipmimages.org/browse/detail.cfm?imgnum=1427014) .

Indirect damage is also caused by the ability of some aphid species to serve as virus vectors. Aphids alone generally do not cause major economic losses in cucurbit crops. However, the viruses transmitted by aphids can cause severe losses. Several mosaic diseases are caused by aphid-transmitted viruses, including cucumber mosaic virus (CMV), watermelon mosaic virus (WMV), zucchini yellow mosaic virus (ZYMV), and papaya ringspot virus (PRSV). Virus diseases often have distinctive symptoms and result in reduced growth and yield. The symptoms of virus infection include mottling, yellowing or curling of leaves, and stunting of plant growth. Under favorable conditions, these viruses can cause a high rate of crop failure and severe economic losses.

Transmission of viruses by aphids is generally of two types: non-persistent and persistent. Aphids acquire non-persistently transmitted viruses after just a few seconds of feeding or probing virus-infected plant tissues with their mouthparts, and can transmit virus to another plant immediately. However, the persistence of the virus in the aphid is very short-lived—only a few minutes. Acquisition of persistently-transmitted viruses requires 10–60 minutes of feeding and, following a 12-hour incubation period, aphids will remain infective for up to their entire life span. In most cases, the green peach aphid and the melon aphid acquire virus by probing or feeding on weeds or other cucurbit crops that are infected. The insects then probe or feed on non-infected crops and transmit the virus. The higher the aphid population, the more rapid the virus spread.

Management of Aphids in Organic Cucurbits

The pest management goal in organic production systems is to design the system so that pests do not find plants, are controlled by natural enemies (biological control), or their damage is kept to a minimum. Vigorous, healthy plants are more able to withstand damage caused by arthropods and disease. Therefore, a “plant positive” (as opposed to “pest negative”) approach to managing the system for beneficial processes and cycles and creating healthy soil and plants, is the foundation of integrated pest management in organic systems.

Cultural Control of Aphids in Cucurbits

A crop rotation plan to proactively manage pests is the foundation of organic crop production. Rotating between crop families can help minimize crop-specific insect pests. Late-season fields should be planted as far away from existing cucurbits as possible. Later plantings and long-season cucurbits are generally most affected by aphid-transmitted mosaic viruses because aphid populations are higher and virus-infected host plants are more available, resulting in more aphids carrying virus. Weeds such as burdock, pokeweed, and other perennial broadleaf weeds can serve as reservoirs for Cucumber Mosaic Virus and Watermelon Mosaic Virus, and should be eliminated.

Plants should be grown with appropriate soil fertility levels. Excessive nitrogen favors aphid reproduction. Application of less soluble forms of nitrogen, in small portions throughout the season rather than all at once, is less likely to promote aphid infestations.

Plants should be inspected for signs and symptoms of an aphid infestation. Special attention should be given to susceptible plant parts where aphids are most likely to establish, such as the undersides of leaves, stems, and buds or tip growth. Also look for honeydew, sooty mold, leaf yellowing, distortion of leaves and new growth, and cast skins produced by molting nymphs. Locations in the field or greenhouse where aphids are found should be flagged, so that population development can be monitored and management efforts evaluated.

Planting non-GMO resistant varieties is one of the primary means of controlling aphid-transmitted viruses. The availability of cucurbit varieties with virus resistance varies depends on the specific virus and cucurbit. Information on resistant cucurbit varieties can be found in Cooperative Extension publications and in catalogs of major seed producers. The source of resistance in some virus-resistant cucurbits is transgenic. Genetically-modified, transgenic varieties are not allowed in organic production systems. Therefore, it is important to verify that the resistant variety being considered is not transgenic.

Physical Control of Aphids in Cucurbits

Many vegetables are most susceptible to aphid damage during the seedling stage. Older plants are more tolerant of aphid feeding. Losses can be reduced by growing seedlings in a greenhouse or under protective covers, such as floating row cover. Protective covers will also prevent transmission of aphid-transmitted viruses. Check transplants for aphids and remove them before planting or destroy infested plants by dropping the plant or infested plant part in a bucket of soapy water, and dispose of them away from the field. To prevent rapid spread of the aphid population in the field, remove and bury, if possi, the few severely infested plants as they appear in spring.

Floating row covers or reflective mulches may help exclude or repel aphids. Aluminum foil mulches can repel invading aphid populations, reducing numbers on seedlings and small plants, and can reduce transmission of aphid-transmitted viruses in summer squashes, melons, and other susceptible vegetables. However, as plants grow, aluminum foil mulches appear to also repel natural enemies of aphids. Because temperatures are higher above foil-mulched plants than above bare soil, aphids that do establish on plants can grow and reproduce at a faster rate. Even so, yields of vegetables grown on aluminum foil mulches are usually higher than those grown on bare soil because of the greater amount of solar energy reflecting on leaves. In very hot or arid areas, reflective mulches can cause conditions that are too warm for good crop growth, and are not recommended.

In small plantings, aphid populations on sturdy plants can be reduced with a strong spray of water. Most aphids dislodged in this way will not return to the plant. Using water sprays should occur early in the day to allow plants to dry to reduce the likelihood of fungal disease of cucurbits. Frequent rain will reduce the number and duration of aphid flights. Heavy rains can also dislodge aphids. Humid conditions favor the development of fungal disease in aphid populations.

Biological Control of Aphids on Cucurbits

Biological control by natural enemies (predators, parasitoids, and pathogens) can have a significant impact on aphid populations. Natural enemies can be conserved through refraining from using broad-spectrum pesticides that kill both pest and beneficial insects. Natural enemy populations can be conserved by creating habitats that provide resources (farmscaping (/pages/18573/farmscaping:-making-use-of-natures-pest-management-services)). Farmscaping methods include the use of insectary plants, hedgerows, cover crops, and water reservoirs to attract and support populations of beneficial organisms such as insects, spiders, amphibians, reptiles, bats, and birds that parasitize or prey upon insect pests. Keeping dust down also encourages parasitism and predation.

Beneficial insects will be attracted to plants with moderate to heavy aphid infestations. These natural enemies may eat large numbers of aphids but the reproductive capability of aphids may be so great that the impact of the natural enemies will not be enough to keep the aphids at or below acceptable levels. Even if aphid populations are reduced to an acceptable level, if virus is present, it may be spread by the few remaining aphids.

Predators catch and eat their prey. Some common aphid predators include:

- Many species of lady beetles and their larvae (e.g., the multicolored Asian lady beetle, *Harmonia axyridis* (http://www.biocontrol.entomology.cornell.edu/predators/Harmonia.html) ; the convergent lady beetle, *Hippodamia convergens* (http://www.biocontrol.entomology.cornell.edu/predators/Hippodamia.html) ; the pink spotted lady beetle, *Coleomegilla maculata* (http://www.biocontrol.entomology.cornell.edu/predators/Coleomegilla.html)
- Minute pirate bug (http://www.biocontrol.entomology.cornell.edu/predators/Orius.html) , *Orius insidiosus* and *O. tristicolor*
- Larvae of the syrphid fly (http://uspest.org/mint/syrphid.htm) (hover fly or flower fly)
- Green (http://www.biocontrol.entomology.cornell.edu/predators/Chrysoperla.html) *Chrysoperla carnea*, *C. rufilabris*, *Chrysopa* spp.) and Brown (http://www.biocontrol.entomology.cornell.edu/predators/Hemerobius.html) (Hemerobius spp.) lacewing larvae
- Larvae of the aphid midge (http://www.biocontrol.entomology.cornell.edu/predators/Aphidoletes.html) (*Aphidoletes aphidimyza*)

Parasitoids (sometimes called parasites) do not usually eat their hosts directly. Adult parasitoids lay their eggs in, on, or near their host insect. When the eggs hatch, the immature parasitoids use the host as food, ultimately killing the host. The parasitized aphid forms a mummy that appears bloated and tan, light brown, or white (Fig. 3). When the weather is warm, the generation time of most parasitoids is quite short. The aphid population is likely to be reduced substantially within a week or two of seeing mummies on plants. Some common aphid parasitoids (Fig. 4) (parasitic wasps) include:

- *Aphidius colemani (http://www.ipm.ucdavis.edu/PMG/NE/aphidius_spp.html)* , *A. matricariae*
- *Lysiphlebus* (http://www.nysaes.cornell.edu/ent/biocontrol/parasitoids/lysiphlebus.html) species
- *Aphelinus* species

(http://www.ipmimages.org/browse/detail.cfm?imgnum=5174013)

Figure 3. Aphid mummy. Figure credit: Nick Dimmock, University of Northampton, Bugwood.org (http://www.ipmimages.org/browse/detail.cfm?imgnum=5174013) .

(http://www.ipmimages.org/browse/detail.cfm?imgnum=5255027)

Figure 4. Aphid parasitic wasp (parasitoid) and aphid mummies. Figure credit: David Cappaert, Michigan State University, Bugwood.org (http://www.ipmimages.org/browse/detail.cfm?imgnum=5255027) .

Fungal Diseases of Aphids

Aphids are very susceptible to fungal diseases (/pages/18928/fungi-for-the-biological-control-of-insect-pests) in humid weather. Fungi that infect insects are found in the environment as spores. Insects can become infected when they come into contact with spores on the surface of plants, in the soil, in the air as windborne particles, or on the bodies of already dead insects. Spores attach to the surface of the insect and infect by penetrating through the insect cuticle. Once inside, the fungus grows throughout the body of the insect, killing the insect in the process. Fungus-infected aphids (http://www.nysaes.cornell.edu/ent/biocontrol/pathogens/fungi.html) appear reddish or brown and have a fuzzy, shriveled texture. Some fungi that infect and provide biological control of aphids, including *Beauveria bassiana*, *Metarhizium anisopliae*, *Verticillium lecanii*, and *Neozygites fresenii*, can provide good biological control of aphids.

Fungal diseases, when they occur, can be more effective than insecticides for controlling large populations of aphids. Fungal spores require high humidity to germinate, and hot, dry weather can inhibit the establishment of fungal disease in an aphid population. However, once established, fungal disease spreads rapidly, creating an epidemic. When an aphid population collapses from a fungal epidemic, populations tend to remain low for the rest of the season. Fungicides used to control plant pathogenic fungi will probably also kill any beneficial fungi present.

Figure 5. *Green peach aphid, Myzus persicae, infected by the fungus, Pandora neoaphidis. Figure credit: Sergio Sanchez, Wikimedia Commons.*

Chemical Control of Aphids in Cucurbits

Products should not be relied upon as a primary method of insect control. Scouting is important for detecting infestations at an early stage. When conditions warrant an application, proper choice of materials, proper timing, and excellent spray coverage are essential (Seaman et al., 2009). Only when all non-chemical practices are insufficient to prevent or control crop pests, may a biological or botanical material allowed for use on organic farms be used. Before applying any pest control product, make sure to include what you might want to use and how you intend to use it in your organic system plan and get your certifier's approval.

(Caution: the use of an unapproved material can result in the loss of certification. Always check with your certifier before purchasing or using a new product or material to ensure that it is permitted for use in your organic farming system. For more information, read the related article, Can I Use This Input On My Organic Farm (/pages/18321/can-i-use-this-input-on-my-organic-farm) ?).

Application of broad-spectrum foliar insecticides will also kill beneficial insects, and allow aphid populations to rebound. This is because most aphids are females that don't need to mate to produce new aphids. The reproduction of natural enemies is slower, often requiring time for mating, egg-laying, and egg hatch.

Insecticidal soaps, azadirachtin, and certain oils are acceptable for use in organically grown crops. Rosemary oil is less disruptive of beneficials than soaps and narrow range oils. They require direct contact with the insects and leave no residual effect.

Major Aphid Pests in Organic Cucurbits

The most common aphid species affecting cucurbits have a large host range and are pests of several horticultural and agronomic crops. These aphids include the green peach aphid (*Myzus persicae*), the melon aphid (*Aphis gossypii*), the potato aphid (*Macrosiphum euphorbiae*), and the bean aphid (*Aphis fabae*).

The Green Peach Aphid (*Myzus persicae*)

(http://www.forestryimages.org/browse/detail.cfm?imgnum=1549259)

Figure 6. Wingless adult green peach aphid giving birth to a nymph. Figure credit: Jim Baker, North Carolina State University, Bugwood.org (http://www.forestryimages.org/browse/detail.cfm?imgnum=1549259) .

The green peach aphid (Fig. 6) is slender, dark green to yellow, and has no waxy bloom. Green peach aphids tend to cluster on the succulent young growth. Development can be rapid, often 10–12 days for a complete generation, and with over 20 annual generations reported in mild climates (Capinera 2005).

Green peach aphid feeds on hundreds of host plants in over 40 plant families. Vegetable hosts include artichoke, asparagus, bean, beets, broccoli, Brussels sprouts, cabbage, carrot, cauliflower, cantaloupe, celery, corn, cucumber, fennel, kale, kohlrabi, turnip, eggplant, lettuce, mustard, okra, parsley, parsnip, pea, pepper, potato, radish, spinach, squash, tomato, turnip, watercress, and watermelon. Field crops such as tobacco, sugar beet, and sunflower also are attacked. Many flower and ornamental plants are suitable for green peach aphid development. Stone fruit crops such as peach are sometimes damaged before the aphids leave for summer hosts. Crops differ in their susceptibility to green peach aphid, but actively growing plants, the youngest plant tissues, the undersides of leaves, or new sheltered growth most often harbor large aphid populations. Green peach aphid does not usually produce high volumes of honeydew. Blemishes to the plant tissue, usually in the form of yellow spots, may result from aphid feeding. Leaf distortions are not common except on the primary host.

Where suitable host plants cannot persist, the aphid overwinters in the egg stage on *Prunus* spp. The eggs are elliptical in shape, initially yellow or green, but soon turn black. In the spring, soon after the plant breaks dormancy and begins to grow, the eggs hatch and the nymphs feed on flowers, young foliage, and stems. Nymphs initially are greenish, but soon turn yellowish, resembling adults. Up to 8 generations may occur on *Prunus* in the spring, but as aphid densities increase winged forms are produced, which then disperse to summer hosts. Winged aphids have a black head and thorax, and a yellowish green abdomen with a large dark patch dorsally. Winged green peach colonize nearly all plants available, often depositing a few young and then taking flight again. This highly dispersive behavior contributes to their effectiveness as vectors of plant viruses. In cold climates, adults return to *Prunus* spp. in the autumn, where mating occurs and eggs are deposited. All generations except the autumn generation reproduce asexually.

The green peach aphid is considered to be the most important vector of plant viruses throughout the world. Nymphs and adults are equally capable of virus transmission. Both persistent viruses and non-persistent viruses, including cucumber mosaic and watermelon mosaic viruses, are effectively transmitted to cucurbits. Broadleaf weeds are suitable host plants for the green peach aphid and can serve as reservoirs for plant virus. Common weeds, such as field bindweed (*Convolvulus arvensis),* lambsquarters *(Chenopodium album*), and redroot pigweed *(Amaranthus retroflexus)*, are important aphid hosts.

The Melon Aphid (*Aphis gossypii*)

(http://www.forestryimages.org/browse/detail.cfm?imgnum=5368257)

Figure 7. Melon aphid. Figure credit: *Merle Shepard, Gerald R.Carner, and P.A.C Ooi, Insects and their Natural Enemies Associated with Vegetables and Soybean in Southeast Asia, Bugwood.org (http://www.forestryimages.org/browse/detail.cfm?imgnum=5368257)* .

The melon aphid (Fig. 7) is also called the cotton aphid. Unlike most other aphids, this small aphid is able to tolerate hot weather, and hot, dry weather can cause populations to increase rapidly. The melon aphid develops in colonies and prefers the underside of leaves, but can also often be found evenly distributed along plant stems. Melon aphid can complete its development and reproduce in as little as a week, so numerous generations are possible when environmental conditions are suitable. The melon aphid is a vector for both non-persistently and persistently transmitted viruses. Fields infested with melon aphid should be disked or plowed under as soon as harvest is complete. Host weeds include milkweed, jimsonweed, pigweed, plantain, and field bindweed (Capinera, 2007).

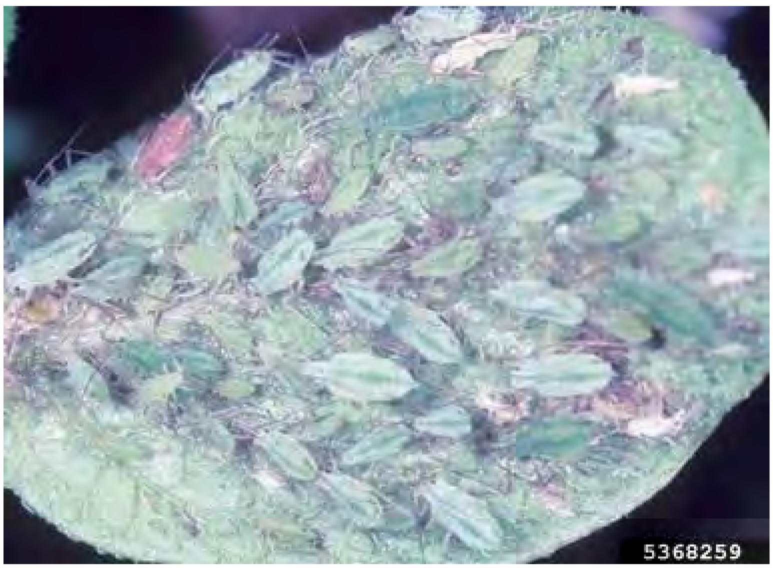
Both winged and wingless forms are produced. The winged individuals are slender and are not as robust as the wingless form. The wingless adults can be yellow, green, black, or dark green and may have white patches on the abdomen. Colonies are often composed of individuals of several colors. Winged adults have black heads and antennae, dark red or black eyes, and an abdomen that is green to dark green with dark patches. The antennae are about one-half the length of the body. The cornicles are dark and always darker than the body.

The life cycle differs between north and south. In the north, female nymphs hatch from eggs on the primary, overwintering host in the spring. The primary hosts in northern locations include catalpa *(Catalpa bignonioides*), and rose of sharon *(Hibiscus syriacus)*. When first deposited, the eggs are yellow, but rapidly become shiny black in color. In the south, females continue to produce offspring without mating as long as weather allows feeding and growth. Overwintering eggs are not commonly produced, but overwintering hosts include dock *(Rumex crispus),* henbit *(Lamium amplexicaule*), boneset *(Eupatorium petaloiduem*), and citrus *(Citrus* spp.).

The nymphs vary in color from tan to gray or green, and often are marked with dark head, thorax, and wing pads, and with the end of the abdomen dark green. The body is dull in color from wax secretions.

The melon aphid may feed, mature, and reproduce asexually on the primary host all summer, or they may produce winged females that disperse to secondary hosts and form new colonies. Under high density conditions, deterioration of the host plant, or upon the arrival of autumn, winged forms are produced. During periods stressful to the host plant, small yellow or white forms of the aphid can be produced. Late in the season, winged females seek primary hosts, where males and egg-laying females are produced. After mating, the females deposit eggs, which are the only overwintering form under cold conditions. Under warm conditions, a generation can be completed asexually in about seven days.

The Potato Aphid (*Macrosiphum euphorbiae*)



(http://www.forestryimages.org/browse/detail.cfm?imgnum=5368259)

Figure 8. Potato aphid. Figure credit: Merle Shepard, Gerald R.Carner, and P.A.C Ooi, Insects and their Natural Enemies Associated with Vegetables and Soybean in Southeast Asia, Bugwood.org (http://www.forestryimages.org/browse/detail.cfm?imgnum=5368259) .

The potato aphid (Fig. 8) may be solid pink, mottled green and pink, or light green with a dark stripe. This aphid is much larger than the green peach aphid, and the adult has longer cornicles and very long legs. Potato aphids infest a wide range of host plants. This aphid can transmit cucurbit viruses. In addition to cucurbits, some important cultivated hosts include potato, tomato, eggplant, sunflower, pepper, pea, bean, apple, turnip, corn, sweet potato, asparagus, clover, and rose. Weeds such as ragweed, lambsquarters, jimsonweed, pigweed, shepherd's purse, and wild lettuce are also common food plants. In northern states, winter is passed in the egg stage on cultivated and wild rose bushes. The eggs hatch in the spring into wingless females which give birth to living young. In the fall, winged aphids fly to the winter hosts and produce females which mate and deposit overwintering eggs. In warm climates, eggs and males are not produced and female aphids feed and reproduce without mating year-round. Nymphs mature in two to three weeks. When overcrowding occurs or food becomes scarce, nymphs develop into winged adults and migrate to new host plants. Multiple generations are produced each year (Natwick et al., 2009).

The Black Bean Aphid (*[Aphis fabae (http://www.arkive.org/black-bean-aphid/aphis-fabae/)](http://www.arkive.org/black-bean-aphid/aphis-fabae/)*)

The black bean aphid is dark olive green to sooty black with light-color legs and its membranous wings are held angled over the body like a tent when at rest. Not all individuals possess wings. This aphid is found mainly on the underside of leaves and only rarely on upper surfaces.

The eggs overwinter on the aphid's primary hosts, *Eunomys* spp., *Viburnum* spp., and *Philadelphius* spp. Winged forms migrate to crop hosts in the spring. On crop hosts, asexual reproduction and live births allow large populations to build up quickly. Winged and wingless forms are produced throughout the summer, allowing dispersal to new plants. In the autumn, aphids migrate to the primary hosts occurs. Sexual females are produced on the winter hosts, mating occurs and females lay eggs which overwinter (Natwick, 2010).

References and Citations

- Capinera, J. L. 2005. Green peach aphid [Online]. University of Florida Featured Creatures No. EENY-222. Available at: http://entnemdept.ufl.edu/creatures/veg/aphid/green_peach_aphid.htm (http://entnemdept.ufl.edu/creatures/veg/aphid/green_peach_aphid.htm) (verified 18 May 2010).
- Capinera, J. L. 2007. Melon aphid [Online]. University of Florida Featured Creatures No. EENY-173. Available at: http://entomology.ifas.ufl.edu/creatures/veg/aphid/melon_aphid.htm (http://entomology.ifas.ufl.edu/creatures/veg/aphid/melon_aphid.htm) (verified 18 May 2010).
- Natwick, E. T., J. J. Stapleton, and C. S. Stoddard. 2009. UC IPM: UC management guidelines for melon aphid on cucurbits [Online]. UC IPM pest management guidelines: Cucurbits, UC ANR Publication 3445, Insects and mites. UC Statewide IPM Program, University of California, Davis. Available at: http://www.ipm.ucdavis.edu/PMG/r116300711.html (http://www.ipm.ucdavis.edu/PMG/r116300711.html) (verified 29 July 2011).
- Natwick, E. T. 2010. UC IPM: UC management guidelines for bean aphid on sugarbeet [Online]. UC IPM pest management guidelines: Sugar beets, UC ANR Publication 3469, Insects and Mites. UC Statewide IPM Program, University of California, Davis. Available at: http://www.ipm.ucdavis.edu/PMG/r735300311.html (http://www.ipm.ucdavis.edu/PMG/r735300311.html) (verified 29 July 2011).

Additional Resources

- Greer, L. 2000. Greenhouse IPM: Sustainable aphid control [Online]. NCAT Sustainable Agriculture Project. Available at: https://attra.ncat.org/attra-pub/viewhtml.php?id=49 (https://attra.ncat.org/attra-pub/viewhtml.php?id=49) (verified 29 July 2011).
- Hollingsworth, C. S. 2009. Pacific northwest insect management handbook [Online]. Available at: http://insects.ippc.orst.edu/pnw/insects (http://insects.ippc.orst.edu/pnw/insects) (verified 29 July 2011).
- Petzoldt, C. 2010. Cucurbits. Chapter 18, Part 1. [Online]. Integrated crop & pest management guidelines for commercial vegetable production. New York State IPM Program. Available at: http://www.nysaes.cornell.edu/recommends/18frameset.html (http://www.nysaes.cals.cornell.edu/recommends/18frameset.html) (verified 29 July 2011).
- Kelley, W. T., and D. B. Langston, Jr. 2009. Commercial production and management of pumpkins and gourds. University of Georgia Cooperative Extension. Bulletin 1180. Available online at: http://www.caes.uga.edu/publications/pubDetail.cfm?pk_id=6279 (http://www.caes.uga.edu/publications/pubDetail.cfm?pk_id=6279) (verified 29 July 2011).
- Nameth, S. T. Mosaic virus diseases of vine crops, HYG-3109-95. Ohio State University Extension Factsheet. Plant Pathology, The Ohio State University, Columbus, OH. Available online at: http://ohioline.osu.edu/hyg-fact/3000/3109.html (http://ohioline.osu.edu/hyg-fact/3000/3109.html) (verified 29 July 2011).
- Randall P. ,and R. P. Griffin. 2009. Cucumber, squash, melon & other cucurbit insect pests. Clemson Cooperative Extension Bulletin No. HGIC 2207. Clemson University. Clemson, SC. Available online at: http://www.clemson.edu/extension/hgic/pests/plant_pests/veg_fruit/hgic2207.html

(http://www.clemson.edu/extension/hgic/pests/plant_pests/veg_fruit/hgic2207.html) (verified 29 July 2011).

- Seaman, A. (ed.) 2011. Production guide for organic cucumbers and squash [Online]. Available at: http://nysipm.cornell.edu/organic_guide/cucurbit.pdf (http://nysipm.cornell.edu/organic_guide/cucurbit.pdf) (verified 29 July 2011).
- Shelton, A. M. Biological control: A guide to natural enemies in North America [Online]. Available at: http://www.nysaes.cornell.edu/ent/biocontrol/ (http://www.nysaes.cornell.edu/ent/biocontrol/) (verified 29 July 2011).

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Cucumber Beetles: Organic and Biorational Integrated Pest Management

A Publication of ATTRA—National Sustainable Agriculture Information Service • 1-800-346-9140 • www.attra.ncat.org

Updated by
Steve Diver and
Tammy Hinman
NCAT Agriculture
Specialists

Cucumber beetles are present throughout the United States and cause serious damage to cucurbit crops. Overwintering adult insects cause feeding damage on young plants, larvae in the soil feed on plant roots and second-generation adults cause feeding damage on plant leaves, blossoms and fruits. Adult insects transmit bacterial wilt and squash mosaic virus. Organic and biorational integrated pest management measures include delayed planting, trap crops, floating row covers, parasitic organisms and botanical pesticides. Field scouting or yellow sticky traps can monitor insect populations.

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Introduction

Cucumber beetles are pests of cucurbits in most areas of the United States. Cucumber beetles transmit bacterial wilt, squash mosaic virus and can increase the incidence of powdery mildew, black rot and fusarium wilt. They also damage plants directly by feeding on roots, stems, leaves and fruits.

This publication will focus on organic and biorational control methods that fit into an integrated pest management approach. Organic control measures include delayed planting, floating row covers, trap crops and using predatory organisms and botanical or biorational insecticides.

Biorational pest controls are commonly known as least-toxic pest controls or soft pesticides. Biorational pest controls are preferred in biointensive integrated pest management because they usually target the pest and spare beneficial organisms, are relatively non-toxic to humans and have few environmental side effects.

Species of cucumber beetles

There are six species of cucumber beetle in the United States. Striped cucumber beetles in the *Acalymma* genus and spotted cucumber beetles in the *Diabrotica* genus are collectively known as diabroticine or diabroticite beetles. The diabroticines, which include the closely related species known as western corn rootworm *(Diabrotica virgifera virgifera)* and northern corn rootworm *(Diabrotica barberi)*, have similar yet distinct ecological and behavioral characteristics. Correctly identifying the pest that occurs in each geographical region is the first step toward devising a pest management strategy.

The striped cucumber beetle is about 1/5 inch long and yellowish-green with a black head and yellow thorax. It has three parallel and longitudinal black stripes along the length of its wing covers. The eastern striped cucumber beetle *(Acalymma vittatum)* is found mostly east of the Mississippi River and the western striped cucumber beetle *(Acalymma trivittatum)* is found mostly west of the Mississippi.

Striped cucumber beetle. *Photo by Ken Gray, courtesy of Oregon State University.*

The spotted cucumber beetle *(Diabrotica undecimpunctata howardi)* is about 1/3 inch long and greenish-yellow with a black head and lime-green thorax. It has 12 black spots on its wing covers. The larval stage is known as the southern corn rootworm.

Spotted cucumber beetle. *Photo by Charles Schurch Lewallen.*

The western spotted cucumber beetle *(Diabrotica undecimpunctata undecimpunctata)* is similar in appearance to the spotted cucumber beetle, but is slightly smaller. It is found in Arizona, California, Colorado and Oregon, though it is more prolific and destructive in the southern part of its range (EPPO, 2003).

Western spotted cucumber beetle. *Photo by Jack Kelly Clark, courtesy of UC Statewide IPM Project, © 2000 Regents, University of California.*

The banded cucumber beetle *(Diabrotica balteata)* is found throughout the southern United States from North Carolina to southern California (Capinera, 1999). It is about 1/5 inch long and greenish-yellow with a red head and black thorax. It has three greenish-blue bands running horizontally across its back and a thin green band along the center of its back.

Banded cucumber beetle. *Photo by Kim Davis and Mike Stangeland,* www.texasento.net/beetles.htm.

Adult western corn rootworms *(Diabroctica virgifera virgifera)* can be found crawling on cucurbit plants, but the rootworms cause little feeding injury to cucurbits and do not transmit bacterial wilt or virus diseases. The female adult looks very similar to a striped cucumber beetle, so it is important to distinguish which insect is present. Striped cucumber beetles have black abdomens underneath the wing cover, while western corn rootworms have yellow abdomens. In addition, the center stripe on the striped cucumber beetle extends to the tip of the abdomen, while the center stripe on the western corn rootworm extends about three-quarters of the way. Finally, striped cucumber beetles have faint yellow markings on their legs while the western corn rootworm has solid black legs.

Adult western corn rootworm. Photo by Jim Kalisch, CropWatch, University of Nebraska-Lincoln Extension.

Related ATTRA publications

Biointensive Integrated Pest Management

Farmscaping to Enhance Biological Control

Organic IPM Field Guide

Organic Pumpkin and Winter Squash Production

Biorationals: Ecological Pest Management Database

Notes on terms used in organic production

Organic production of crops and livestock in the United States is regulated by the U.S. Department of Agriculture's National Organic Program. The program is an organic certification and marketing program that ensures food and food products labeled as organic meet standard guidelines. Land must be free of synthetic pesticides and fertilizers for three years before it can be certified organic. After that, producers can only use approved organic pest control strategies and fertilizers.

Producers who want to label or market their produce as organic need to gain certification through a USDA-accredited certifying agent. This process involves the development of an organic system plan describing details about soil fertility planning, seeds and seedlings, weed and pest management practices including materials the grower plans to use, and storage and handling routines (Kuepper, 2002). A recordkeeping system and an annual farm inspection are also required.

For more information, see the ATTRA publication *Organic Farm Certification and the National Organic Program.* Please note that farmers involved with organic certification should check with an accredited certifying agent before using any pest control material mentioned in this publication, whether it is described as organic or biorational, to verify approved status.

Biorational products include botanicals, horticultural oils, insecticidal soaps, biopesticides (biofungicides and microbial antagonists), mineral-based products, parasitic nematodes, anti-feedants, plant extracts and pheromones. Organic farmers commonly use biorational product formulations of natural origin.

Biorational pest controls also include reduced-risk pesticides and insect growth regulators that are not allowed in organic production. In addition, organic farmers are not allowed to use certain botanical insecticides like nicotine and rotenone or specific formulations of biorational pesticides. For example, the commercially available Entrust formulation of spinosad is allowed, but many other spinosad formulations are not.

The Organic Materials Review Institute is a nonprofit organization that reviews products used in organic crop production for the purpose of fertility and plant stimulation, as well as for weed, insect and disease control. Manufacturers submit product data, ingredients and related proprietary information to the institute for evaluation of suitable materials according to standards established by the USDA National Organic Program.

The OMRI Products List is a directory of products reviewed and approved by the institute for use in organic crop production. These products may display the **OMRI Listed** seal on labels and in advertising literature. The OMRI Products List is a convenient way for farmers to identify which biorational pest control products are approved for use in organic production.

Resources:

The National Organic Program
USDA – Agricultural Marketing Service
www.ams.usda.gov/nop/indexNet.htm

The OMRI Products List
Organic Materials Review Institute
www.omri.org

Organic regulation, certification, transition and history
ATTRA – National Sustainable Agriculture Information Service
www.attra.ncat.org/organic.html

Life cycle of the cucumber beetle

Understanding the life cycle of an insect pest is critical to using control measures effectively. Integrated pest management pest-control strategies require knowledge of the pest's life cycle to:

- Adjust planting times so crops are not in a susceptible growth stage when the pest is most active
- Distract insects from susceptible crops by using pheromones or trap crops
- Disrupt the pest's ability to reproduce or grow

Applications of biorational insecticides are most effective and least costly when based on knowledge of:

- The pest's life cycle
- The life stage(s) of the pest that will damage the crop plant
- The life stage(s) of the crop plant most susceptible to the pest
- The life stage of the pest that is easiest to control
- Local climate and ecological conditions and how they affect plant growth and insect movement

Refer to the ATTRA publication *Biointensive Integrated Pest Management* for an introduction to integrated pest management concepts and practices.

Cucumber beetles overwinter as unmated adults in bordering vegetation, plant debris, woodlots and fence rows. Cucumber beetles are active in spring when temperatures reach 55 to 65 degrees Fahrenheit and feed on alternate host plants until cucurbit plants appear in vegetable fields.

Striped cucumber beetles are monophagous during the larval stage, meaning the beetles only feed on roots of cucurbit plants. Overwintering adults feed on the pollen, petals and leaves of early blooming plants, especially flowering plants in the rose family, in spring before migrating to cucurbit fields. Adults also feed on the leaves and flowers of corn, beans and peas during the growing season and on goldenrods, sunflowers and asters later in the season. However, both species of striped cucumber beetles are known as specialist feeders because the beetles highly prefer cucurbit plants and fruits. The beetles produce one or two generations per growing season in northern regions and two or three generations in southern regions.

High-altitude currents can carry striped cucumber beetles up to 500 miles in three to four days.

Spotted cucumber beetles are polyphagous during the larval stage, meaning the beetles feed on the roots of multiple host plants. The larvae are commonly known as rootworms because they are injurious feeders on roots of corn, peanuts, small grains and grasses. Adult spotted cucumber beetles feed on the pollen, petals and leaves of more than 200 alternate host plants. Adult spotted cucumber beetles overwinter in southern states and migrate into northern states in June and July, appearing two to four weeks later than striped cucumber beetles. Adults are strong fliers and disperse rapidly from field to field during summer. High-altitude currents can also carry striped cucumber beetles up to 500 miles in three to four days. (EPPO, 2003). Spotted cucumber beetles produce two or three generations in a growing season.

The banded cucumber beetle is polyphagous during the larval stage and can be an injurious feeder on roots of soybeans and sweet potatoes in addition to cucurbits. Adult banded cucumber beetles feed on a wide range of plants in the cucurbit, rose, legume and mustard families. Banded cucumber beetles can produce up to seven generations per year in the Deep South.

After feeding and mating on cucurbit seedlings, female cucumber beetles oviposit eggs in the soil near the base of plants. Egg production ranges from 200 to 300 eggs per female, laid in clusters over the course of several weeks, for the spotted cucumber beetle and up to 1,500 eggs per female for the striped cucumber beetle. Eggs usually hatch in five to 10 days with larval development from 11 to 45 days. Pupae reside in the soil for four to seven days and then emerge as adults. Depending on weather and temperature, peak activity can spike every 30 to 60 days as new generations emerge. Adults can live up to 60 days or more (Capinera, 2001).

Damage to plants by cucumber beetles

Cucumber beetles injure cucurbit crops directly and indirectly. Direct feeding by larvae can injure crop roots and disrupt plant growth. Direct feeding by adults can stunt seedlings and damage maturing fruits. Cucumber beetles transmit bacterial wilt, which causes plants to quickly wilt and die. Bacterial wilt is a major problem for many vegetable growers.

Feeding damage

Cucumber beetles inflict feeding damage three times during their life cycle:

- Overwintering adults feed on emerging cucurbit plants in the spring. These adults can kill or severely stunt young plants by feeding on stems and cotyledons. Adult cucumber beetles also transmit bacterial wilt.
- Larvae from eggs laid by overwintering adults feed on plant roots. Larval tunneling can stunt crop plants, especially seedlings, and predispose the plant to soilborne diseases such as fusarium wilt.
- Second- and third-generation adults emerging from pupae during the

growing season or migrating into the area at mid-season feed on foliage, flowers, stems and fruit. These adults damage maturing fruits and transmit bacterial wilt. Feeding damage is less serious to plants that are already leafed out. Damage to fruits results in scarring and decreases the marketability and storage life of the crop.

Cucumber beetles preferentially feed on different cucurbit species. The approximate order of susceptibility to feeding damage may vary with geographical regions.

Some varieties of a cucurbit species are more attractive to cucumber beetles than others. For example, cucumber beetles preferentially feed on muskmelon varieties in the following order, from greatest to least (Foster et al., 1995):

1. Makdimon	6. Galia
2. Rocky Sweet	7. Pulsar
3. Cordele	8. Passport
4. Legend	9. Super Star
5. Caravelle	10. Rising Star

See Table 1, *"Ranking of cucurbits by cucumber beetle feeding preference,"* for susceptibility ratings of other cucurbit species.

Vegetable Insect Management with Emphasis on the Midwest **(Foster et al., 1995) lists susceptibility, from greatest to least as:**

1. Cucumber
2. Cantaloupe
3. Honeydew
4. Casaba melon
5. Winter squash
6. Pumpkins
7. Summer squash
8. Watermelon

Jude Boucher from the University of Connecticut ranks susceptibility in the northeast from greatest to least as:

1. Bitter gourds
2. Winter squash *(C. maxima)* such as Turk's Turban, Blue Hubbard, etc.
3. Cucumbers
4. Summer squash
5. Cantaloupe
6. Honeydew
7. Butternut winter squash
8. Casaba melon
9. Watermelon

Table 1. Ranking of cucurbits by cucumber beetle feeding preference (Jarvis, 1994).

Higher ranking numbers indicate more preferred varieties by cucumber beetles. Rankings: 1 to 14 means not preferred, greater than 45 means highly preferred.

Summer squash		Winter squash	
Variety	**Ranking**	**Variety**	**Ranking**
Yellow		***Acorn***	
Sunbar	1	Table Ace	6
Slender Gold	2	Carnival	7
Early Prolific Staightneck	20	Table King (bush)	12
Goldie Hybrid	32	Tay Belle (bush)	14
Sundance	33	***Butternut***	
Straightneck		Zenith	13
Seneca Prolific	4	Butternut Supreme	16
Goldbar	5	Early Butternut	25

Table 1. *Continued*			
Higher ranking numbers indicate more preferred varieties by cucumber beetles. Rankings: 1 to 14 means not preferred, greater than 45 means highly preferred.			
Summer squash		**Winter squash**	
Multipik	37	Waltham	28
Crookneck		***Buttercup***	
Yellow Crookneck	8	Honey Delight	43
Sundance	34	Buttercup Burgess	44
Scallop		Ambercup	55
Peter Pan	9	***Pumpkins***	
Zucchini		Baby Pam	10
Gold Rush	39	Munchkin	11
Zucchini Select	40	Seneca Harvest Moon	15
Ambassador	41	Jack-Be-Little	17
President	45	Jackpot	18
Black Jack	46	Tom Fox	19
Green Eclipse	50	Baby Bear	21
Seneca Zucchini	51	Howden	22
Senator	52	Spirit	23
Super Select	54	Wizard	24
Dark Green Zucchini	56	Ghost Rider	26
Embassy Dark Green Zucchini	57	Big Autumn	27
Other summer squash		Autumn Gold	29
Scallop	3	Jack-of-All Trades	30
Cocozelle	48	Rocket	31
Caserta	58	Frosty	35
Melon		Spookie	36
Classic	59	Connecticut Field	38
		Happy Jack	42
		Big Max	47
		Baby Boo	53

Bacterial wilt

In addition to direct feeding on plants, cucumber beetles are vectors for bacterial wilt caused by the bacterium *Erwinia tracheiphila*. While foliage-feeding adult cucumber beetles can injure crops, especially seedlings, the transmission of bacterial wilt disease is a more serious concern because the disease causes rapid wilting and death of cucurbit plants.

While horticultural literature commonly explains that bacterial wilt overwinters in the intestinal tract of adult cucumber beetles, plant pathologists now believe the *Erwinia* bacterium overwinters in the sap of alternate host plants. These plants remain asymptomatic, or do not exhibit symptoms of the disease (Latin, 2000). Adult cucumber beetles feed on these alternative host crops, become infected with bacterial wilt and then transmit the disease to squash, melons or cucumbers by feeding on the crop plants or through fecal contamination of wounded leaves and stems.

Following infection, the *Erwinia* bacterium spreads throughout the vascular system of the plant, causing blockage of xylem vessels. The formation of bacterial-exuded gums and resins results in restricted movement of water and nutrients and the plant starts to wilt. The incubation period from time of infection to expression of wilting symptoms ranges from several days to several weeks. Young, succulent plants are more susceptible to cucumber beetle feeding and disease transmission than older, mature plants.

To determine if a plant is infected with bacterial wilt, use the following diagnostic tests:

- Squeeze sap from a wilted stem cut near its base. Press a knife against the stem and slowly pull it away about a centimeter. The appearance of fine, shiny threads indicates bacterial wilt (Snover, 1999).
- Immerse a newly cut stem in a glass of water. If the plant has bacterial wilt, milky strands of bacterial ooze will leak from the stem in five to 10 minutes.
- Cut the stem with a knife and then push the cut ends together and slowly pull them apart. Sticky, viscous strands of bacterial slime indicate bacterial wilt (Latin, 2000).

The sap of a healthy plant is watery and will not exhibit stringing and bacterial oozing (Snover, 1999).

Bacterial wilt is most severe on cantaloupe and cucumber, less damaging on squash and pumpkin and rarely affects established watermelon plants. Wilt-resistant varieties are available for some cucurbits, but still lacking for others. For example, County Fair 83 and Saladin are resistant varieties of cucumber, but resistant varieties of muskmelon are not developed.

Squash mosaic virus

The western striped cucumber beetle and the spotted cucumber beetle are alternate vectors for another disease: squash mosaic virus. Aphid insects are the primary vector. While the virus is seed-borne, the incidence of this disease is enhanced through cucumber beetle feeding and transmission. Squashes and melons are particularly susceptible to this disease because of a greater occurrence of infected seeds in these species.

The symptoms of squash mosaic virus vary according to host species and cultivar, but include mosaic patterns, leaf mottling, ring spots, blisters and fruit deformation (Provvidenti and Haudenshield, 1996). Besides the use of certified virus-free seeds, control measures are aimed at minimizing the presence of cucumber beetles. (Provvidenti and Haudenshield, 1996 and Davis et al., 1999).

Bacterial wilt is most severe on cantaloupe and cucumber, less damaging on squash and pumpkin and rarely affects established watermelon plants.

Organic control measures

Organic control measures for cucumber beetles fall into five categories, each discussed in detail in the following sections:

- Population monitoring
- Cultural practices
- Trap crops, trap baits and sticky traps
- Predators and parasites
- Botanical and biorational insecticides

Population monitoring methods like crop scouting and sticky traps are commonly used as monitoring tools to help growers detect insect pest populations and make informed and timely pest management decisions. Growers can use threshold data established by university Extension entomologists to determine when control measures, like a knock-down insecticide, prevent crop damage and disease transmission.

Cornell University recommends crop scouting twice a week, with emphasis on the inspection of young cucurbit plants with fewer than five leaves. Monitoring should involve thorough inspection of five plants at each of five locations in a field. Pay special attention to the undersides of leaves and plants at field edges. These population counts are used to calculate the average number of beetles per plant (Petzoldt, 2008).

Economic thresholds for cucumber beetle control depend on the type of cucurbit, age of plants and susceptibility to bacterial wilt. Once cucurbit vines are well-established, plants can tolerate a 25 to 50 percent loss of foliage without a reduction in yield. However, seedling cucurbits can be seriously injured or killed by heavy feeding from cucumber beetles. When bacterial wilt is present, risk is greater among cucurbit varieties that are most susceptible. Entomologists in the Midwest use a threshold of one beetle per plant for insecticidal control when bacterial wilt disease is present.

Growers can use homemade yellow sticky traps or purchase commercial yellow sticky cards for detection of cucumber beetles. Homemade and commercial insect attractants can enhance the trapping effect. Cucumber beetles and most insets are attracted to the color yellow.

To make a simple sticky trap, coat an 8-ounce yellow plastic cup with insect glue, like commercially available Stickum Special or Tangle-Trap. Invert the cup and secure it on a 2-foot wooden stake (Levine and Metcalf, 1988). Eugenol, a naturally occurring insect attractant found in clove oil (82 to 87 percent eugenol), allspice oil (65 to 75 percent eugenol) and bay oil (40 to 45 percent eugenol), lures diabroticine beetles (Peet, 2001 and The Scientific Community on Cosmetic and Non-food Products, 2000). Cinnamaldehyde, found in cassia oil and cinnamon bark oil, functions as an insect attractant and natural cucumber beetle bait (Environmental Protection Agency, 2007). Attach a cotton swab soaked in these aromatic oils to increase the sticky trap's trapping effect.

Integrated pest management suppliers sell rectangular yellow sticky cards imprinted with grid patterns for detection of diabroticine beetles. These include the Pherocon AM trap card from Trece, Inc., the Intercept AM trap card from Advanced Pheromone Technologies, Inc., the ISCA yellow sticky card from ISCA Technologies, Inc. and the Olson yellow sticky card from Olson Products, Inc. These products are listed under the **Products** section of **Resources** at the end of this publication.

Researchers at Southwest-Purdue Agricultural Center in Vincennes, Ind., determined that 20 striped or spotted cucumber beetles per trap during a 48-hour period correspond to one beetle per plant. That is the threshold for treating cucurbits in the Midwest, especially with melons and cucumbers, to prevent excessive loss from bacterial wilt (Lam and Foster, 2005). If fewer than 20 beetles are found on the traps, it means that beetle populations are not at an economic threshold and treatment is not warranted. Growers should repeat this monitoring procedure through critical parts of the growing season.

Volatile chemicals known as kairomones attract diabroticine beetles. Kairomones include cucurbatacins, indoles and floral volatiles as well as specific kairomonal analogs like 2,3-benzopyrrole and 1,2,4-trimethoxybenzene. Since each species of cucumber beetle responds to unique kairomones, separate commercial lures are available for each type of cucumber beetle. There are two manufacturers of kairomone lures: Trece, Inc., which sells the Pherocon CRW series, and Advanced Pheromone Technologies, Inc., which sells the APTLure series.

Cultural practices are land and crop management practices that affect the reproduction of pests or the time and level of exposure crops have to pests. Cultural practices that can protect against cucumber beetles include:

- Delayed planting
- Floating row covers
- Mulching
- Cultivation and residue removal
- Insect vacuuming

Crop rotation within a field, a well-known pest management tool for disease control, is ineffective to control cucumber beetles since the beetles migrate from areas surrounding the fields. Since these insects survive on a number of wild hosts, the removal of alternative hosts from the farm would be difficult and ineffective because of immigration. A two-year study in Massachusetts compared the effectiveness of synthetic and biorational insecticides on the control of striped cucumber beetles and the occurrence of bacterial wilt in direct-seeded and transplanted pumpkin using the susceptible Merlin variety. Results of the trial indicate the need for long-distance crop rotation for insecticides to be most effective. Rotation to an adjacent field close to the pervious year's cucurbits did not reduce beetle numbers (Andenmatten et al., 2002).

Delayed planting is an effective pest management strategy in some regions and cropping systems. Growers can avoid the first generation of cucumber beetles by keeping fields cucurbit-free until the establishment of summer cucurbits like cucumbers, pumpkins and squash intended for fall harvest. Delayed planting is an especially useful cultural strategy in cucurbits because this technique also bypasses first-generation squash bugs. However, this method is not relevant for plantings of early-market spring cucurbits like cucumbers, squash and melons or in regions with short growing seasons.

Floating row covers physically exclude both cucumber beetles and squash bugs during the seedling stage of plant growth. Providing a bug- and beetle-free period allows the plants to thrive and develop a mass of leaf and vine growth by the time row covers are removed at bloom. At this stage of vegetative growth, plants can withstand moderate pest attacks. In regions with established cucumber beetle populations, row covers can make the difference between a harvestable crop and crop failure. Row covers are removed at the onset of flowering to allow for bee pollination and to release vine growth. Applying botanical and biorational pesticides provides season-long protection, depending on location and pest pressure, after row covers are removed.

Weed control is a special consideration when using floating row covers over cucurbit seedlings in bare, moist soil. Row covers create a favorable environment for the germination and growth of weeds. Periodic removal of row covers for mechanical cultivation to stir the soil and disrupt weed seedlings is not very practical. Row covers are normally used for the first 30 to 40 days of vine growth until the onset of flowering. This corresponds to the critical weed-free period for cucurbit plant growth, when weeds should be controlled and excluded as much as possible. In organic production, row covers are commonly used in combination with weed-suppressive mulches like plastic mulch, geotextile weed barriers, straw, hay and paper.

Mulching can deter cucumber beetles from laying eggs in the ground near plant stems. Mulches can also function as a barrier to larval migration and feeding on fruits (Cranshaw, 1998 and Olkowski, 2000). Tunneling larvae need moist soil to damage ripening fruit. Limiting irrigation at this time can minimize damage (Cranshaw, 1998). Mulches are known to harbor squash bugs, however, and mulches do not deter beetles from feeding on leaves, flowers and fruits of cucurbits.

Researchers at Virginia Tech showed a dramatic reduction in the occurrence of striped cucumber beetles in a Meteor cucumber crop and similar reductions in both striped and spotted cucumber beetles in a General Patton squash crop by comparing aluminum-coated and aluminum-striped plastic mulches to black plastic mulch (Caldwell and Clarke, 1998). On various sampling dates, yellow sticky traps located next to the aluminum-coated plastic mulches had two, four and six times less cucumber beetles than stick traps located next to black plastic mulch. Researches, after correlating the number of beetles found on sticky traps to the integrated pest management threshold, concluded that reflective mulches reduced cucumber beetle populations to below treatment levels.

The Virginia Tech research article contains a brief economic comparison between costs of production and prices received for

In regions with established cucumber beetle populations, row covers can make the difference between a harvestable crop and crop failure.

organic squash versus conventional squash gown on reflective mulches. Researchers emphasized the ability of reflective mulches to reduce bacterial wilt and virus transmission by cucumber beetles and aphids.

Cultivation and residue removal can help reduce over-wintering populations of cucumber beetles. Cornell University research suggests deep tillage and clean cultivation following harvest (Petzoldt, 2008). However, an organic farming sequence that shreds crop residues, incorporates fall-applied compost or manure and establishes a winter cover crop will facilitate decomposition of above- and below-ground residues.

Insect vacuuming is a form of pneumatic insect control that dislodges insects from plants through high-velocity air turbulence and suction. Large, mechanized bug vacs gained notoriety in the 1980s for control of the lygus bug in California strawberry fields. Hand-held and backpack vacuuming equipment is available through integrated pest management suppliers. Market farms use the equipment to collect beneficial insects and control pest insects in combination with perimeter trap cropping.

The D-Vac, a commercially available vacuum, evolved from insect sampling research by the biological control pioneer Everett Dietrick (Dietrick et al., 1995). Insect vacuuming combined with perimeter trap crops is an appealing non-chemical control strategy. Researchers have employed this dual technique in attempts to control flea beetles in brassica fields (Smith, 2000). This dual technique has also been suggested for mass trapping of cucumber beetles followed by vacuuming as a pest reduction strategy and as an alternative to insecticide applications (Olkowski, 2000). The next section explains how pheromones attract cucumber beetles to perimeter trap crops where beetles congregate in great numbers. The efficacy of this dual technique for control of cucumber beetles is not verified in field trials and is mentioned here as an experimental approach that organic market farmers may wish to explore.

Entomologist Sam Pair inspects squash plants for cucumber beetles and squash bugs lured to this trap crop and away from developing melons.
Photo by Scott Bauer, USDA-ARS 2008.

Trap crops, trap baits and sticky traps, if positioned correctly, can intercept beetles through the use of smell, color and pheromonal attraction.

Trap crops release chemicals known as kairomones, which are highly attractive to insects. Kairomones produced by cucurbits include cucurbitacin, the characteristic bitter substance in cucurbitacae that stimulates compulsive feeding behavior in diabroticine beetles, and a mixture of floral volatiles that lure adult beetles from some distance.

Cucurbit trap crops are designed to lure and concentrate cucumber beetles where control measures using insecticides or vacuuming can be focused, reducing the need for field-scale insecticide applications.

Pioneering research in the 1970s and 1980s by Robert L. Metcalf (Ferguson et al., 1979) in Illinois, as well as more recent research in Texas, Oklahoma, Maine, Connecticut and Virginia, shows that certain species and varieties of cucurbits can serve as trap crops next to larger fields of cucurbits (Stroup, 1998, Suzkiw, 1997, Radin and Drummond, 1994, Boucher and Durgy, 2004 and Caldwell and Stockton, 1998). Diabroticine beetles preferentially congregate, feed and mate on these kairomone-effusive trap crops. *Table 1* ranks the feeding preference of cucumber beetle on different varieties of cucurbits.

Researchers at Cornell University found cucumber beetles highly prefer the following varieties of *Cucurbita maxima* and *Cucurbita pepo* squash and pumpkin types (Grubinger, 2001):

Black Jack zucchini
Big Max pumpkin
Cocozelle summer squash
Green Eclipse zucchini
Seneca zucchini
Senator zucchini
Baby Boo pumpkin
Super Select zucchini
Ambercup buttercup squash
Dark Green zucchini
Embassy Dark Green zucchini
Caserta summer squash
Classic melon

Researchers elsewhere used Lemondrop summer squash, Peto 391 summer squash, NK530 squash, Blue Hubbard squash and Turk's Turban squash. However, experience shows that cucurbit varieties highly susceptible to bacterial wilt, such as Turk's Turban, should be avoided as a trap crop (UMass Extension, 2002).

Early research in Maine examined the percentage of land devoted to the trap crop. When researchers grew NK530 squash as a trap crop on 15 percent and 50 percent of the cucumber crop acreage, the trap crop attracted 90 percent of the cucumber beetles (Radin and Drummond, 1994). The researchers concluded that strategically placed strips of squash plants could be more advantageous.

In Oklahoma, Lemondrop and Blue Hubbard squash planted as trap crops and occupying just 1 percent of the total crop area highly attracted cucumber beetles in cantaloupe, squash and watermelon crops (Pair, 1997). The Oklahoma researchers also showed that small squash plants in the four- to six-leaf stage are vastly more effective as trap crops than large squash plants in the more-than-six- to 12-leaf stage, which corroborates findings that cucurbitacin occurs in higher concentrations in young leaves. Recent integrated pest management field trials suggest that perimeter trap cropping, where border rows encompass all four sides of the field, is a pragmatic and an effective approach (Boucher and Durgy, 2004 and Boucher and Durgy, 2005).

To deter entry into the field by cucumber beetles and minimize the spread of bacterial wilt:

- Plant trap crops on the perimeter of the field as border strips. Plant multiple rows if beetle pressure is extreme.
- Plant trap crops a week or two earlier than the primary cucurbit acreage since insects migrate to the earliest emerging cucurbit plants in the field.
- In organic production, apply botanical and biorational insecticides to the trap crop before the beetles migrate into the cucurbit patch. In integrated pest management production, several synthetic insecticides can be applied to the trap crop for beetle control. Vacuuming is a novel approach to controlling beetles that congregate on the trap crop.
- Use yellow sticky ribbons in combination with trap crops to enhance the attractant effect and perform mass trapping.
- Remove and destroy diseased plants from border strips and the main field.

Trap baits for cucumber beetles contain insect-attracting kairomones, floral volatiles, buffalo gourd root powder, eugenol, cinnamaldehyde and cinnamyl alcohol mixed with small amounts of insecticides. Metcalf and coworkers pioneered the identification of cucurbitacin analogs used in attracticidal baits (Metcalf and Lampman, 1991).

Trap baits on field borders intercept beetles as beetles migrate into cucurbit fields early in the season. Great numbers of beetles die when they are lured into these attracticidal baits in a feeding frenzy. Cidetrak CRW is a commercially available gustatory stimulant for diabrotica that growers can mix with synthetic or biorational insecticides in a trap bait. It is available through Trece, Inc., a company that specializes in pheromone traps. See the **Products** section listed under **Resources** for Trece, Inc. contact information. While most of the field trials and commercial applications with attracticidal baits employed systemic insecticides, Michael P. Hoffman at Cornell University investigated the use of trap baits in combination with botanical and biorational insecticides and cultural controls (1998).

Hoffmann's field trials in New York were part of a USDA Sustainable Agriculture Research and Education research project to reduce insecticide use in cucurbit crop production (Hoffman, 1998). Employing a mass-trapping technique, Cornell researchers reduced cucumber beetle populations by 65 percent in pumpkin fields using trap baits containing a mixture of cucurbit blossom volatiles and very small amounts of insecticide. Researchers found positioning trap baits with a highly preferred Seneca zucchini squash trap crop enhanced trap baits, achieving 75 percent control with this dual method.

Researchers found positioning trap baits with a highly preferred Seneca zucchini squash trap crop enhanced trap baits, achieving 75 percent control with this dual method.

In support of organic production, the project examined the effectiveness of botanical and biorational pesticides. The researchers used buffalo gourd root powder as a feeding stimulant in trap baits laced with neem and full or half rates of rotenone (botanical) and cryolite (sodium aluminoflouride). Neem had little effect on beetle survival or mortality, but its antifeedant trait significantly reduced plant damage caused by beetles. Rotenone and cryolite were both effective.

Overall, researchers favored the half-rate of rotenone mixed with buffalo gourd root powder treatment. However, in the interim period since Hoffmann's research in 1999, both of these biorational products were prohibited in organic production under the National Organic Program. Neither is listed with the Organic Materials Review Institute. It seems reasonable that other biorationals approved for organic production might be effectively used in a trap bait.

Yellow sticky traps are commonly used to monitor insect pests. Yellow sticky ribbon is available from commercial integrated pest management suppliers in dimensions of 2 to 12 inches wide by several hundred feet in length. In cucurbits, yellow sticky ribbon can be used for mass trapping of cucumber beetles when placed with cucurbit trap crops. Kairomone lures, available through commercial integrated pest management suppliers, can enhance the trapping effect.

William Olkowski, co-founder of the Bio-Integral Resource Center, conducted an Organic Farming Research Foundation-funded study on mass trapping of cucumber beetles using six different framed and strip traps.

The Bio-Integral Resource Center Trap, a wooden-legged trap that held upper and lower strips of yellow sticky ribbon 10 feet long and oriented parallel to the ground, was highly effective in trapping cucumber beetles. The 6-inch wide yellow sticky ribbon is mounted on a spool and requires periodic uptake to expose fresh sticky tape. Since the upper strip, located 20 to 26 inches above the ground, captured far more cucumber beetles than the lower strip, located 12 to 18 inches above the ground, researchers discontinued the lower strip in later trials. The trap is mobile and can be placed in cucurbit trap crops.

The *OFRF Information Bulletin No. 8*, published in the summer of 2000, is available as a Web download and is useful to develop an understanding of how to design and use the trap (Olkowski, 2000).

Predators and parasites that prey on cucumber beetles include hunting spiders, web-weaving spiders, soldier beetles, carabid ground beetles, tachinid flies, braconid wasps, bats and entomopathogenic fungi and nematodes. Braconid wasps *(Centisus diabrotica, Syrrhizus diabroticae)* and tachinid flies *(Celatoria diabroticae, C. setosa)* are important natural enemies of cucumber beetles, with parasitism rates reaching 22 percent and 40 percent, respectively (Capinera, 2001 and Kuhlmann and van der Burgt, 1998). Carabid beetles *(Scarites* spp. and *Evarthrus sodalis)* consumed all three life stages (larvae, pupae, adults) of spotted cucumber beetle, striped cucumber beetle and squash bugs in a laboratory feeding trial (Snyder and Wise, 1999). Biological control from natural enemies varies widely between locations and is not dependable as the only control strategy in commercial cucurbit production. Providing beneficial insect habitat can enhance cumulative biocontrol results in organic farming systems.

David H. Wise and co-workers in the department of entomology at the University of Kentucky thoroughly investigated spider predation of cucumber beetles (Snyder and Wise, 2000, Williams et al., 2001 and Williams and Wise, 2003). Wise found that both striped and spotted cucumber beetles reduce their feeding rate and emigrate from cucurbit plants in the presence of the large wolf spiders *Hogna helluo* and *Rabidosa rabida.* Spider presence reduced plant occupancy of diabroticine beetles by 50 percent. Curiously, adult female beetles are far more responsive to the presence of wolf spiders and alter their behavior to avoid capture. Consequently, males were 16 times more likely than females to be killed by *R. rabida* in one experiment; only 5 percent of males survived a two-day exposure to *H. helluo* in a second experiment. In general, populations of predaceous spiders and ground beetles can be enhanced through habitat modification using straw mulch (Snyder and Wise, 1999), straw shelters (Halaj et al., 2000) and beetle banks (Master, 2003).

Bats are voracious eaters of insects and more farmers are erecting bat houses to enhance biological control of crop pests. John O. Whitaker, Jr., a vertebrate ecologist at Indiana State University, used data partly derived from studies on the evening bat *(Nycticeius humeralis)* to estimate that a typical Midwestern colony of 150 big brown bats *(Eptesicus fuscus)* might consume 38,000 cucumber beetles, 16,000 June bugs, 19,000 stink bugs and 50,000 leafhoppers in one season (Whitaker, 1993).

In a detailed follow-up study where he dissected fecal pellets of big brown bats from Indiana and Illinois, Whitaker calculated that a colony of 150 bats might consume 600,000 cucumber beetles, 194,000 scarabaeids, 158,000 leafhoppers and 335,000 stinkbugs in one season. Assuming that half of the cucumber beetles were female, and using a value of 110 eggs per female, this means the potential destruction of 33 million diabrotica larvae (Whitaker, 1995).

Male wolf spider. Photo by Patrick Edwin Moran, Courtesy of Creative Commons.

An April-June 2006 article in *California Agriculture* evaluated the best way to attract bats to farms through the placement, shape, size and color of bat houses (Long et al., 2006). For more information about creating on-farm bat habitat and the use of insectary plantings to attract beneficial insects, see the ATTRA publication *Farmscaping to Enhance Biological Control.*

Entomopathogenic fungi, commonly grouped among biopesticides, produce infective spores that attach to the larval host and then germinate and penetrate. The fungi multiply inside the host, acquiring nutrient resources and producing conidial spores. This causes the infected larvae to reduce their feeding and die, releasing fungal spores into the soil environment and further distributes the entomopathogen.

The two fungal organisms most widely used as biopesticides, *Beauveria bassiana* and *Metarhizium anisopliae,* have been evaluated for suppression of diabroticine larvae with varying levels of biocontrol. Mycotrol-O is a commercially available, Organic Materials Review Institute-approved biopesticide containing *Beauveria bassiana* and cucumber beetle is listed as a target pest on the label. See the section on **botanical insecticides** below with notes from Reggie Destree for foliar mixtures containing Mycotrol-O.

Entomopathogenic nematodes, commonly known as parasitic nematodes, actively find and penetrate soil-dwelling larvae of insect pests. The nematodes release toxins and transmit bacteria that is lethal to the larval host. Both species of commercially available parasitic nematodes, *Steinernema* spp. and *Heterorhabditis* spp., are effective in biological control of diabroticine beetle larvae.

Researchers in Pennsylvania obtained a 50-percent reduction in striped cucumber beetle larvae using *Steinernema riobravis* in organic and conventionally managed plots of cucumbers under field conditions (Ellers-Kirk et al., 2000). The decrease in cucumber beetle larval populations resulted in superior root growth under both soil management systems.

Nematodes release toxins and transmit bacteria that are lethal to insect pests' larvae.

The researchers suggested delivery of parasitic nematodes through drip irrigation in combination with plastic mulch, since earlier studies showed that plasticulture provides an environment conducive to nematode survival while increasing effective control of cucumber beetle larvae.

The Insect Parasitic Nematode Web site, developed and maintained by the department of entomology at The Ohio State University, contains information on the biology and ecology of nematodes and how to use them for pest control in different crops (Grewal, 2007). It features an extensive list of commercial suppliers of parasitic nematodes.

Based on results from seven published studies, Dr. David Shapiro-Ilan, a research entomologist with the USDA Agricultural Research Service in Georgia, found that parasitic nematodes provide approximately 60 percent control of diabrotica larvae (Shapiro-Ilan, 2006 and Grewal et al., 2005). Ilan added that it is important to put entomopathogens, whether fungi or nematodes, in perspective. Since diabroticine beetles migrate in from surrounding borders, these biological control measures have little effect on adult beetle feeding and disease transmission. However, decreasing larval populations through the use of entomopathogens can have a cumulative biocontrol effect in organic farming systems.

Botanical and biorational insecticides like azadarachtin, an extract from the neem tree, have anti-feedant and insecticidal properties. Alone, azadarachtin is not effective against adult cucumber beetles. However, recent studies by Reggie Destree, a crop consultant, indicate that a mixture of neem with karanja oil derived from the tree *Pongamia glabra*, which grows in India, can reduce cucumber beetle populations by 50 to 70 percent overnight (personal communication). Alone, neem oil applied as a soil drench acts as an ovicide and is effective against larval damage (Destree, 2006). Please see the **Products** section in **Resources** below for sources of commercial neem and karanja products.

Destree recommends a three-part management regime for cucumber beetles:

- The neem blend described above has a dual mode of action. It is a systemic product that will suppress insects that feed on the plant and it has fungicidal properties.
- Use 1 pint Cedar ACT cedar oil to 10 gallons water as a repellent or pheromone disruptor during the first flight of the cucumber beetle in May and the second flight in September. Exact dates depend on location. Destree advises applying the mixture every five to seven days when the fields are square or short rectangles. Pheromone disruption does not work well for long, narrow fields. Adding Cedar ACT to the weekly foliar program works well.
- Mycotrol-O is a commercially available mycoinsecticide formulation containing spores of the entomopathogenic fungus *Beauveria bassiana* GHA strain. Use Mycotrol to suppress future populations. Destree found this program works well for all overwintering insects. A fall soil treatment of the Mycotrol-O added to a fall residue program will insure that the active ingredient, *Beauvarria bassiana*, will be reproducing in the soil and will eventually infect

overwintering beetles in the soil (Destree, 2006).

ATTRA note: Reggie Destree is a crop consultant and distributes the above products. This information has not been validated by university-based research.

The botanical pesticides sabadilla, rotenone or pyrethrum have moderate effectiveness in controlling cucumber beetles (Caldwell et al., 2005). Sabadilla is toxic to bugs and honey bees, and sabadilla should not be applied when bees are present. Pyrethrum is also toxic to all insects, including beneficial species. These botanical pesticides are also highly toxic to fish until degraded (King County Hazardous Waste Program, 1997).

One way to enhance the effectiveness of these materials while reducing overall management costs is to combine the materials with perimeter trap cropping so that sprays can be concentrated on the border. See the above section on trap cropping for more on this topic. Some growers use pyrethrum or rotenone in combination with the commercially available particle film barrier Surround WP Crop Protectant (Grubinger, 2001). Note that rotenone is currently not approved by the National Organic Program.

Results of a two-year study comparing the effectiveness of insecticides on management of striped cucumber beetles and bacterial wilt in direct seeded and transplanted pumpkin showed the need for long-distance crop rotation for insecticides to be most effective. When the rotation was to an adjacent field in different land, but close to the previous year's cucurbits, it did not reduce beetle numbers and insecticide effectiveness tended to decline (Andenmatten et al., 2002).

Particle film barriers provide a promising new approach to insect control for organic producers. Surround WP acts as a repellent, mechanical barrier and irritant, and disrupts the beetles' host-finding abilities. The active ingredient in this product is specially processed kaolin clay, an edible mineral used as an anti-caking agent in processed foods and products like toothpaste. According to the former product representative for Surround WP, John Mosko of the Engelhard Corporation, kaolin clay provides good suppression of cucumber beetles. He recommends:

- Using an air blast sprayer to achieve good coverage
- Applying the product under the leaves where cucumber beetles congregate
- Applying Surround WP early in the growing season before cucumber beetle populations increase. Surround can provide remedial control of cucumber beetles, but field trials show early applications deter beetles from initially entering the field and are more effective
- Reapplying after a heavy rain
- Continually agitating the solution while applying it
- Cleaning harvested fruits with a moist cloth or a post-harvest rinse to remove any film residue of the kaolin clay left on the crop after harvest

Ruth Hazzard with the University of Massachusetts Extension recommends using Surround WP Crop Protectant in combination with other tactics like rotation, row cover, using transplants so plants are bigger when beetles arrive, and delaying planting until late June to avoid beetles. Surround can be applied to transplants before setting them in the field (Andenmatten et al., 2002). See the **Products** section of **Resources** below for information on how to obtain this product.

The timing and usage of either botanical or chemical insecticides should be based on observed population thresholds or measured risks of population build-up. Determining when spring flight begins forecasts the arrival of cucumber beetles in each geographical region.

Only treat hot spots or areas of high infestations if possible. Insecticide applications made between dawn and dusk, when the striped cucumber beetle is most active, may be more effective.

For more information on biorational insecticides, or formulations with little or no long-lasting environmental impact, see ATTRA's online Biorationals: Ecological Pest Management Database, *http://attra.ncat.org/index.html.*

Resources

Information:

Bio-Integral Resource Center (BIRC)
For a publications catalogue, contact:
P.O. Box 7414
Berkeley, CA 94707
510-524-2567
510-524-1758 fax
birc@igc.apc.org
www.birc.org

The Bio-Integral Resource Center is a leader in the field of integrated pest management. BIRC publishes the IPM Practitioner and Common Sense Pest Quarterly. They also publish a directory of IPM products and beneficial insects and offer booklets and reprints on least-toxic controls for selected pests.

Insect Parasitic Nematodes

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www.oardc.ohio-state.edu/nematodes/default.htm

This Web site provides information on the biology and ecology of parasitic nematodes, how to use nematodes to control plant diseases and a comprehensive listing of companies that sell nematodes.

Hunter, C.D. 1997. *Suppliers of Beneficial Organisms in North America.* California Environmental Protection Agency. Department of Pesticide Regulations Environmental Monitoring and Pest Management Branch
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www.cdpr.ca.gov/docs/ipminov/bensup.pdf

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References:

Andenmatten, Hazzard, R, Howell, J. Wick, R. 2002. Management strategies for Striped Cucumber Beetle and Bacterial Wilt in Pumpkin, 2001 & 2002. UMass Extension Vegetable Program. *www.umassvegetable.org/soil_crop_pest_mgt/pdf_files/management_strategies_for_striped_cucumber_beetle_and_bacterial_wilt_in_pumpkin_2001_2002.pdf*

Boucher, T. J. and R. Durgy. 2004a. Demonstrating a Perimeter Trap Crop Approach to Pest Management on Summer Squash in New England. Journal of Extension, October 2004, Volume 42 Number 5. *www.joe.org/joe/2004october/rb2.shtml*

Boucher, T. J. and R. Durgy, 2004b. Perimeter Trap Cropping for Yellow and Green Summer Squash. University of Connecticut, Integrated Pest Management. *www.hort.uconn.edu/Ipm/veg/htms/sumsqshptc.htm*

Boucher, T. J. and R. Durgy 2005. Directions for Using a Perimeter Trap Crop Strategy to Protect Cucurbit Crops. University of Connecticut, Integrated Pest Management. *www.hort.uconn.edu/ipm/veg/htms/directptc.htm*

Caldwell, B. et al. 2005. Resource Guide for Organic Insect and Disease Management. New York State Agricultural Experiment Station.

Caldwell, J. S. and P. Clarke. 1998. Aluminum-coated plastic for repulsion of cucumber beetles. Commercial Horticulture Newsletter, January–February 1998. Virginina Cooperative Extension, Virginia Tech. *www.ext.vt.edu/news/periodicals/commhort/1998-02/1998-02-01.html*

Caldwell, J. S. and S. Stockton. 1998. Trap Cropping in Management of Cucumber Beetles. Commercial Horticulture Newsletter, Virginia Tech, July-August 1998. *www.ext.vt.edu/news/periodicals/commhort/1998-08/1998-08-04.html*

Capinera, J. L. 1999. Banded Cucumber Beetle. Featured Creatures. University of Florida, Department of Entomology and Nematology. *http://creatures.ifas.ufl.edu/veg/bean/banded_cucumber_beetle.htm*

Capinera, J. 2001. Handbook of Vegetable Pests. Academic Press, New York.

Cranshaw, W. 1998. Pests of the West. Revised: Prevention and Control for Today's Garden and Small Farm. Fulcrum Publishing, Golden, CO.

Davis, R.M. et al. 1999. Squash mosaic virus. In: M.L. Flint (ed.) U.C. IPM Pest Management Guidelines: Cucurbits. University of California, Division of Agriculture and Natural Resources, Oakland.

Destree, R. 2006. Organic Marketing by Reggie. E-mail Communication August 2006.

Dietrick, E. J., J. M. Phillips, and J. Grossman. 1995. Biological Control of Insect Pests Using Pest Break Strips, A New Dimension to Integrated Pest Management. California Energy Commission and the Nature Farming Research and Development Foundation, Lompoc, California. 39 p.

Ellers-Kirk, C.D., S.J. Fleischer, R.H. Snyder and J.P. Lynch. 2000. Potential of entomopathogenic nematodes for biological control of *Acalymma vittatum (Coleoptera: Chrysomelidae)* in cucumbers grown in conventional and organic soil management systems. Journal of Economic Entomology. Vol. 93, No. 3. p. 605–612.

Environmental Protection Agency. 2007. Floral Attractants, Repellents, and Insecticides Fact Sheet. *www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_florals.htm*

EPPO. 2003. Diabrotica undecimpunctata. EPPO Data Sheets on Quarantine Pests, European and Mediterranean Plant Protection Organization. *www.eppo.org/QUARANTINE/insects/Diabrotica_undecimpunctata/DIABUN_ds.pdf*

Ferguson, J. E., Metcalf, R. L., Metcalf, E. R., Rhodes, A.M. 1979. Bitter cucurbita spp. as attractants for diabroticite beetles. Cucurbit Genetics Cooperative Report. Volume 2. *http://cuke.hort.ncsu.edu/cgc/cgc02/cgc2-23.html*

Foster, R., G. Brust, and B. Barrett. 1995. Watermelons, Muskmelons, and Cucumbers. In: Rick Foster and Brian Flood (eds.) Vegetable Insect Management with Emphasis on the Midwest. Meister Publishing Company, Willoughby, OH.

Grewal, P.S., R.U. Ehlers, and D.I. Shapiro-Ilan (Editors). 2005. Nematodes as Biocontrol Agents, CABI Publishing, Wallingford, UK. 528 p.

Grewal, P. 2007 (updated). Insect Parasitic Nematodes. Department of Entomology, Ohio State University. *www.oardc.ohio-state.edu/nematodes*

Grubinger, V. 2001. Reports from the Field. Vermont Vegetable and Berry News, July 1, 2001. University of Vermont *www.uvm.edu/vtvegandberry/newsletter/07012001.html*

Halaj, J., A.B. Cady, and G.W. Uetz. 2000. Modular habitat refugia enhance generalist predators and lower plant damage in soybeans. Environmental Entomology. Vol. 29, No. 2. p. 383–393.

Hoffman, M. P. 1998. Developing Sustainable Management Tactics for Cucumber Beetles in Cucurbits. Northeast Regional SARE, ANE95-022. *www.sare.org/reporting/report_viewer.asp?pn=ANE95-022&ry=1999&rf=1*

Jarvis, W.R. 1994. Bacterial wilt. In: Ronald J. Howard, J. Allan Garland, and W. Lloyd Seaman (eds.) Diseases and Pests of Vegetable Crops in Canada. The Canadian Phytopathological Society and the Entomological Society of Canada, Ottawa, Ontario.

King County Hazardous Waste Program, WA. 1997. Pyrethrum. Local hazardous waste management program in King County. *www.govlink.org/hazwaste/house/yard/problems/chemical.cfm?entityID=123&ModeID=631&grp=chemrem*

Kuepper, George. 2002. Organic Farm Certification and the National Organic Program. ATTRA/ NCAT Publication #IP222. National Center for Appropriate Technology.

Kuhlmann, U. and W. A.C.M. van der Burgt. 1998. Possibilities for biological control of the western corn rootworm, *Diabrotica virgifera virgifera* LeConte, in Central Europe. Biocontrol News and Information. Vol. 19, No. 2. p. 59N–68N. *www.pestscience.com/PDF/KUHLM.PDF*

Lam, W. and Foster, R. 2005. An Integrated Pest Management Program for Cucumber Beetles on Muskmelons. Purdue University. Department of Entomology.

Latin, R. X. 2000. Bacterial Wilt. APSnet Feature Story. October 5 through October 31, 2000. Contributed by R. X. Latin, Purdue University. *www.apsnet.org/online/feature/pumpkin/bacterial.html*

Levine, E. and R. Metcalf. 1988. Sticky attractant traps for monitoring corn rootworm beetles. The Illinois Natural History Survey Reports, No. 279.

Long, R. F., W. M. Kiser, and S. B. Kiser. 2006. Well-placed bat houses can attract bats to Central Valley farms. California Agriculture. April-June. p. 91–94. *http://californiaagriculture.ucop.edu/0602AMJ/pdfs/7_BatHouses.pdf*

Master, S. D. 2003. Evaluation of Conservation Strips as a Conservation Biological Control Technique in Golf Courses. M.S. Thesis, University of Maryland. 131 p.

Metcalf, R.L. and R.L. Lampman. 1991. Evolution of Diabroticite rootworm beetle (Chrysomelidae) receptors for cucurbita blossom Volatiles. Proc. Nat. Acad. Sci. Vol 88. p. 1869–1872.

Necibi, S.B., A. Barrett, and J. W. Johnson. 1992. Effects of a black plastic mulch on the soil and plant dispersal of cucumber beetles, Acalymma vittatum (F.) and Diabrotica undecimpunctata howardi Barber (Coleoptera: Chrysomelidae), on melons. J. Agric. Entomol. Vol. 9. p. 129–135.

Olkowski, W. 2000. Mass trapping western spotted cucumber beetles. OFRF Information Bulletin No. 8 (Summer). Organic Farming Research Foundation, Santa Cruz, CA. p. 17–22. *http://ofrf.org/publications/news/IB8.PDF*

Pair, S.D. 1997. Evaluation of systemically treated squash trap plants and attracticidal baits for early-season control of striped and spotted cucumber beetles

(Coleoptera:Chrysomelidae) and squash bug (Hemiptera:Coreidae) in cucurbit crops. Journal of Economic Entomology. Vol. 90, No. 5. p.1307–1314.

Peet, M. 2001. Insect pests of vegetable crops in the Southern United States: Striped and Spotted Cucumber Beetle. Sustainable Practices for Vegetable Production in the South. *www.cals.ncsu.edu/sustainable/peet/IPM/insects/pests.html*

Petzoldt, C. 2008. Chapter 18, Part 2, Cucurbits: Insects and Weeds. Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production, Cornell University. *www.nysaes.cornell.edu/recommends/18cucurbits_1.html*

Provvidenti, R. and J.S. Haudenshield. 1996. Squash Mosiac. In: Thomas A. Zitter, Donald L. Hopkins, and Claude E. Thomas (eds.) Compendium of Cucurbit Diseases. American Phytopathological Society Press, St. Paul, MN.

Radin A.M., F.A. Drummond. 1994. An evaluation of the potential for the use of trap cropping for control of the striped cucumber beetle, Acalymma vittata (F.) (Coleoptera: Chrysomelidae). Journal of Agricultural Entomology. Vol. 11. p. 95–113.

The Scientific Community on Cosmetic and Non-food Products. 2000. The First Update of the Inventory of Ingredients Employed in Cosmetic Products. Section II: Perfume and Aromatic Raw Materials. The Scientific Committee on Cosmetic Products and Non-Food Products Intended for Consumers. *www.leffingwell.com/cosmetics/out131_en.pdf*

Shapiro-Ilan, D. 2006. Southeast Fruit and Nut Research Laboratory, USDA-ARS, Byron, GA. Personal communication.

Smith, R. 2000. Evaluating trap crops for controlling flea beetle in brassicas, and an organic pesticide trial. OFRF Information Bulletin No. 8 (Summer). Organic Farming Research Foundation, Santa Cruz, CA. p. 9–13.

Snover, K. L, 1999. Bacterial Wilt of Cucurbits: *Erwinia tracheiphila*. Plant Disease Diagnostic Clinic Fact Sheet. Cornell University. *http://plantclinic.cornell.edu/Factsheets/bactwiltccbits/bactwiltccbits.htm*

Snyder, W.E., and D.H. Wise. 1999. Predator interference and the establishment of generalist predator populations for biocontrol. Biological Control. Vol. 15. p. 283–292.

Snyder, W.E. and D.H. Wise. 2000. Antipredator behavior of spotted cucumber beetles (Coleoptera: Chrysomelidae) in response to predators that pose varying risks. Environmental Entomology. Vol. 29. p. 35–42.

Stroup, J. M. 1998. Cucurbit Insect Pest Population Densities as Influenced by Tap Crop Use in Watermelon. M.S. Thesis, Tarleton State University, Stephenville, Texas. 65 p.

Suzkiw, J. 1997. Melon Growers' Next Battle Cry Against Insect Pests Could be Squash 'Em! Agricultural Research, USDA-ARS, September 1997. *www.ars.usda.gov/is/AR/archive/sep97/trap0997.htm*

UMass Extension. May 2002. Striped Cucumber Beetle and Bacterial Wilt Management in Vine Crop. University of Massachussetts Extension. *www.umassvegetable.org/soil_crop_pest_mgt/pdf_files/striped_cucumber_beetle_and_bacterial_wilt_management_in_vine_crops.pdf*

Whitaker, J.O., Jr. 1993. The status of the evening bat, *Nycticeius humeralis,* in Indiana. Proc. Indiana Acad. Sci. Vol. 102. p. 283–291.

Whitaker, J.O., Jr. 1995. Food of the big brown bat Eptesicus fuscus from maternity colonies in Indiana and Illinois. American Midland Naturalist. Vol. 134, No. 2. p. 346–360.

Williams, J.L., W.E. Snyder and D.H.Wise. 2001. Sex-based differences in antipredator behavior in the spotted cucumber beetle (Coleoptera: Chrysomelidae). Environmental Entomology. Vol. 30. p. 327–332.

Williams, J.L, and D.H. Wise. 2003. Avoidance of wolf spiders (Araneae: Lycosidae) by striped cucumber beetles (Coleoptera: Chrysomelidae): laboratory and field studies. Environmental Entomology. Vol. 32. p. 633–640.

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Updated by Tammy Hinman
NCAT Agriculture Specialist

Holly Michels and Karen Van Epen, Editors
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