ORGANIC AND SUSTAINABLE SEEDLING PRODUCTION: A Guide for Specialty Crop Growers

Introduction

This grower guide describes how to efficiently and effectively grow vegetable and flower seedlings for organic operations using environmentally responsible practices. It begins with a brief overview of greenhouse structures and the basic cultural requirements and environmental management techniques needed to optimize germination and seedling development.

It then addresses topics that many small-scale California organic producers have identified as of greatest interest in producing seedlings: soil mixes and containers, seeding and irrigation options, fertility, pest and disease control, and system efficiencies.

Growing your own organic seedlings offers many advantages, including control over varieties, quantities, and timing. Seedling production requires knowledge of ideal conditions for successful germination and seedling development, as well as an investment in infrastructure, appropriate equipment, materials, and considerable labor.

Greenhouse Structures

Greenhouse structures provide plants with shelter and protection from the elements. Their environments can be moderated and controlled, allowing for high density growing under ideal conditions. Greenhouse structures are extremely valuable, even in the milder climate locations across much of California, because they allow growers to influence temperature and manage moisture delivery to optimally meet the needs of plants across different stages of their life cycles.

The type of structure you use should ultimately be based on finances, climate, and the types of crops you grow. Whichever type of structure you choose, proper orientation is very important. Structures should ideally have an east/west orientation, such that the long side faces south, for optimal environment enhancement.

If you're starting from scratch, think about the location of your greenhouse—a central location makes it possible for activities to efficiently radiate out from the site. Consider road access in your planning process to more easily bring in materials and move seedlings out to fields and gardens.

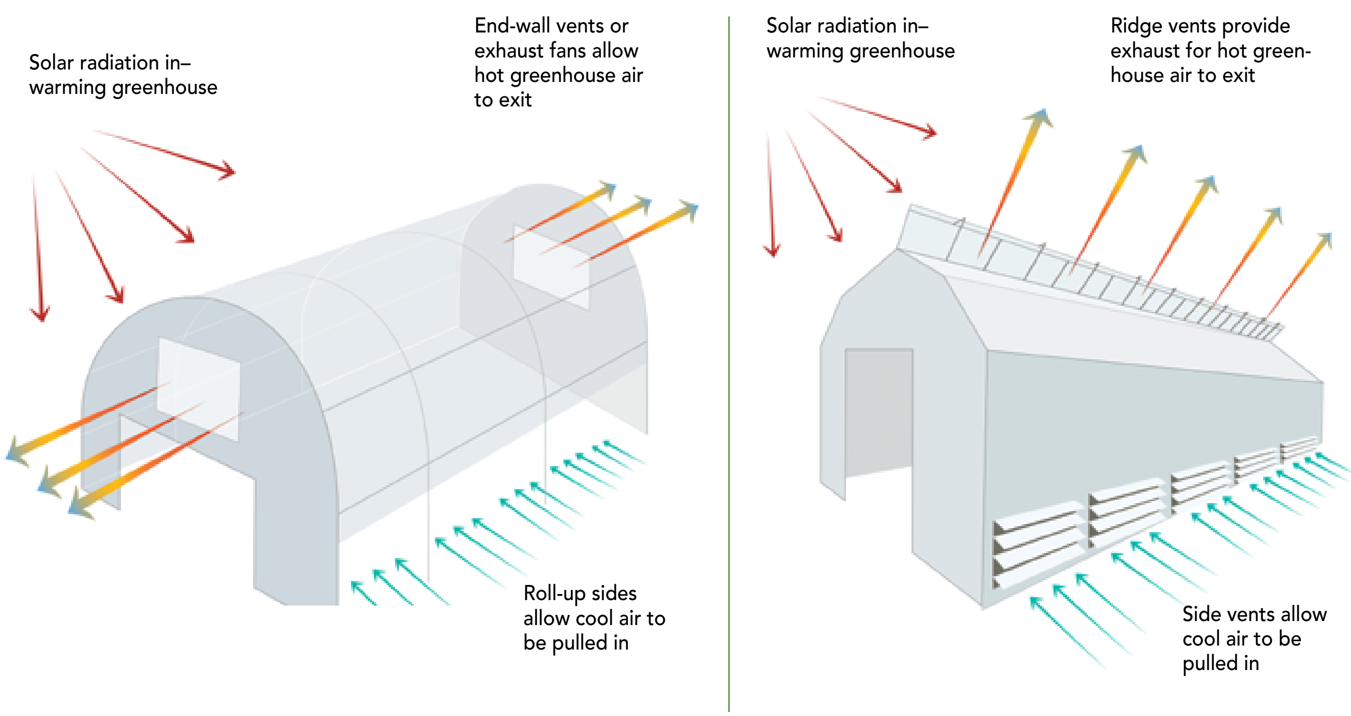
Methods of Environmental Control

Passive methods of environmental control represent a low-tech approach that does not involve continual use of energy to regulate conditions. Passive methods can substantially improve the growing environment but do not enable complete control of it. Examples include capturing the sun's energy as solar radiation for heating, using whitewash or shade cloth to reduce light intensity and inside temperatures, and facilitating both cooling and air circulation with side, endwall, and ridge vents.

Active environmental controls use an energy source such as electricity or natural gas to power heating, cooling, venting, supplemental lighting, irrigation, and climate control systems. Active control mechanisms are not a substitute for passive methods, but rather are complementary tools that allow growers to more precisely and predictably create desired conditions.

The "Greenhouse Management" section of *Teaching Organic Farming & Gardening: Resources for Instructors* (casfs.ucsc.edu/about/publications/Teaching-Organic-Farming/PDF-downloads/1.3-propagation.pdf) and *Ball Redbook: Greenhouses and Equipment* (see the "Additional Resources" section of this guide) are excellent resources with more information on greenhouse structures.

Hoophouse Passive Heating and Cooling Mechanisms



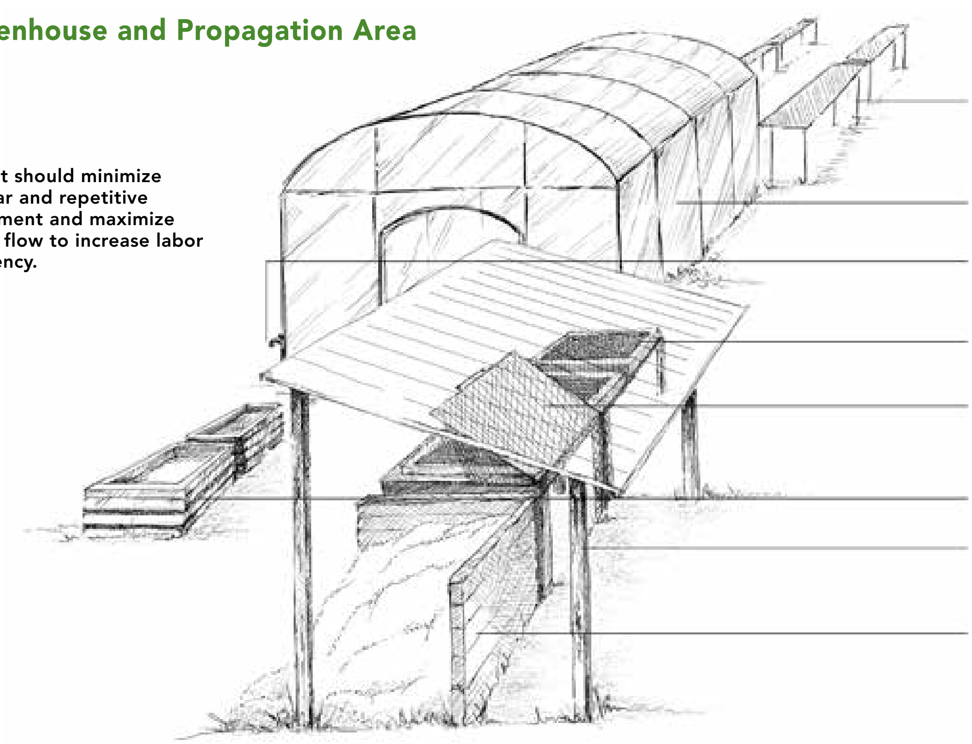
Workspace Design

Thoughtful design of your workspace can optimize your system efficiencies and minimize time spent on each task. When setting up your workspace, try to minimize and streamline all materials handling and repetitive motions.

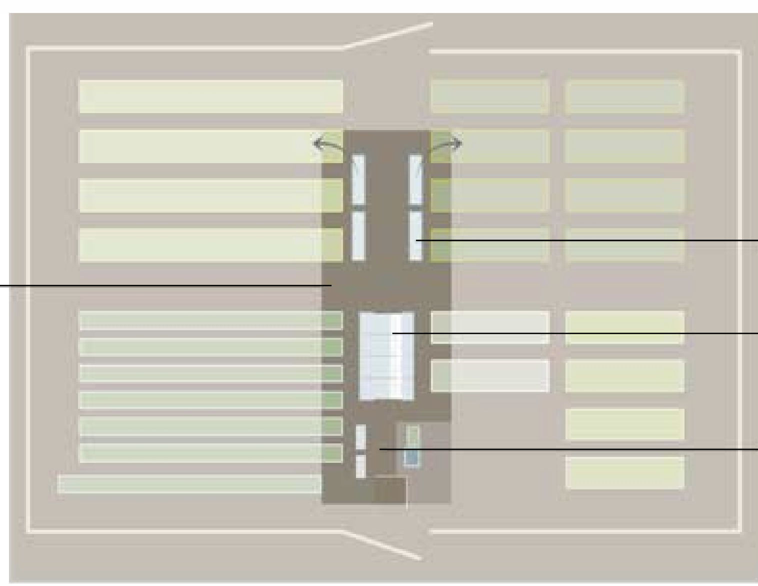
For example, store your soil mixes and seedling containers in close proximity to where you fill your containers, sow your seeds in a space that is easily accessible from where containers are filled, and seek the most efficient pathway from your sowing location to where seeds will germinate in the greenhouse. Move multiple trays at a time into the greenhouse to save time and energy. A few seconds saved with each task adds up to considerable time savings over the course of the season.

Using a vacuum seeder can greatly increase sowing efficiency, thus saving considerable labor input. See the graph comparing the efficiency and cost of hand sowing versus vacuum seeding on page 12 to see how building or investing in a vacuum seeder might be right for your operation.

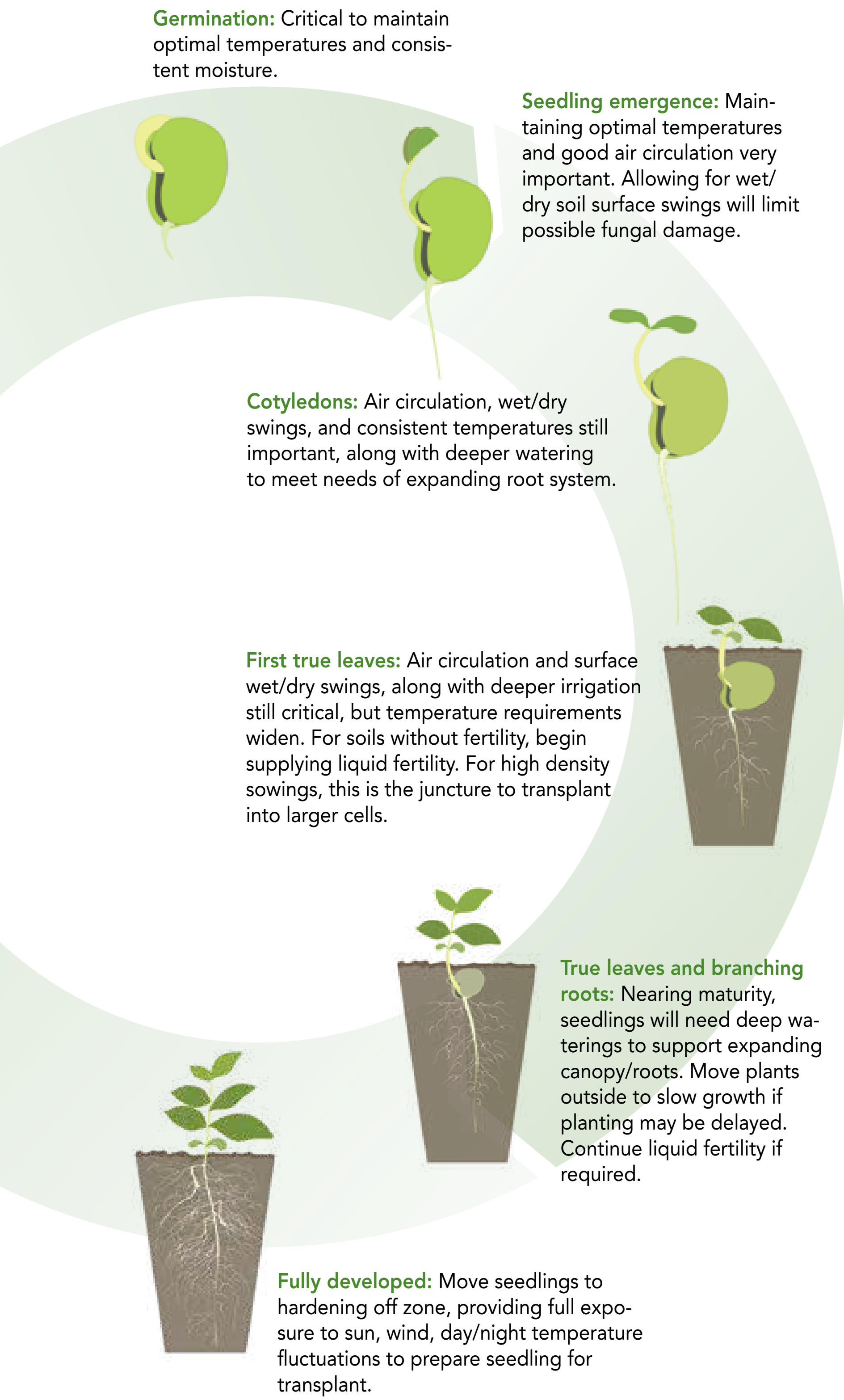
Greenhouse and Propagation Area



Farm Schematic



Basic Cultural Requirements for Germination and Seedling Development



Whether you opt for passive or active methods to control the environment of your greenhouse structure, attention to proper temperature, moisture, aeration, light, and fertility is required for successful seed germination and seedling development.

Temperature

Every crop has an optimal temperature at which the germination percentage is highest and the number of days to emergence is lowest (see "Soil Temperature Conditions for Vegetable Seed Germination," casfs.ucsc.edu/documents/Teaching Organic Farming/appendix3-soiltemp.pdf). This is the target range to strive for when managing greenhouse facilities.

Warm season crops such as tomatoes, peppers, eggplant, summer squash, and cucumbers germinate best when air and soil temperatures are 75–78°F. Most cool season crops germinate best when air and soil temperatures are in the mid 60°s F. In a greenhouse with both warm and cool season crops, aim for a temperature in the low 70°s F. This middle ground is cool enough for almost all cool season crops and warm enough for warm season crops.

It is also possible to control the temperature of only certain areas in the greenhouse with heat mats and other methods of microclimatic heating that aim to heat the root zone only or by utilizing the differing microclimates/temperature zones that already exist in many greenhouses. For example, using the south side of a space for warm season crops will keep those crops warmer, and placing cool season crops near vents will keep those crops cooler.

Soil and air temperatures are most critical during the time of germination until the time of seedling emergence. This is where a germination chamber or heat mats can be useful, particularly for warm season crops. Once germinated, most seedlings can tolerate a wider range of temperatures, ideally around the mid 70°s for warm season crops and mid 60°s for cool season crops.

Moisture

For most seeds, soil mixes should be maintained at or above 50%–75% of container capacity (see "Greenhouse Irrigation Concepts and Terms," page 15) during the germination phase, be well-aerated, and have a fine texture to provide good seed-to-soil contact. There are some ex-

GERMINATION CHAMBERS

These small-scale, self-contained facilities consist of a water-holding pan, a submersible heat source with variable temperature control, a water supply, and walls enclosing the germination area. Germination chambers provide optimal control over temperature and humidity to facilitate rapid, high-percentage germination in a compact space. Once seedlings germinate, be sure to immediately remove propagation trays from the lower light levels of the chamber and move them to a sunny location to avoid stretching and legginess in your seedlings.

FIGURE 1. DIY germination chamber made with repurposed materials to keep costs affordable.

ceptions to the above moisture rule, including crops such as cucumbers, melons, squash, and sunflower, which tend to like a more substantial wet/dry swing. Excessive irrigation and/or poorly drained soil media can limit germination and development or allow damping off fungi to proliferate when oxygen is crowded out of the pore spaces by constant moisture (see “Pest and Disease Management,” page 18).

As seedlings develop, irrigation frequency typically decreases while the depth and volume of water delivered at each irrigation should increase, which supports the expanding root system and leaf canopy and matches the increase in transpiration that naturally occurs as seedlings develop. Reduced irrigation frequency and the resulting enhanced wet/dry swing help reduce susceptibility to damping off fungi and promote the plant’s ability to cope with short-term moisture limitations.

Air Circulation

Consistent air circulation provides adequate oxygen for respiration and mitigates against the presence of fungal pathogens. The ability to promote good circulation should be built into the design of a growing structure and is ultimately about using venting systems and fans (if your greenhouse structure has them) to circulate air within the structure, draw in fresh air, and exhaust air back outside. With the vents open in a well-designed house, the entire volume of air can be exchanged in a matter of minutes, making for better surface soil aeration, moisture exchange, and an environment where pathogens are far less likely to damage your crops.

Light

Most species germinate best in darkness and should be shallowly covered with your soil medium or a moisture retaining ingredient like vermiculite. Certain seeds, such as those of Dusty Miller and feverfew, should be left on the soil surface to prevent them from being buried too deeply when irrigated. Other seeds, such as ageratum, begonia, and coleus, require light to germinate and should also be left uncovered.

After germination, sunlight is critical for all developing seedlings to manufacture nutrients through photosynthesis and to promote strong cellular growth and compact architecture. If germination takes place in a low light environment, such as a germination chamber, seedlings should be moved into the greenhouse early or late in the day when light intensity is lower so that the transition to full sun will be relatively gradual.

Nutrient Availability

During the germination phase, seeds rely on stored nutrients for their initial development. Subsequent development depends on providing balanced nutrients to support roots and shoots and to promote healthy, uninterrupted growth. Excess fertility can lead to lush, rangy growth and attract aphids and other insects that feed on nitrogen-rich crops. Inadequate fertility can lead to weak, stunted growth, limited root development, an undersized canopy, premature flowering, and delays in seedling maturation.

Soil Mixes

Whether you buy commercial soil mixes or blend your own, it’s important to find the right mix to create an ideal environment for germination and seedling development.

Soil mixes should:

- Provide a readily available nutrient supply to support steady, healthy plant growth, unless you will provision for fertility by way of soluble sources when you irrigate (see “Supplemental Fertility,” page 15)
- Retain adequate moisture, allow excess water to drain rapidly, and provide for proper aeration to promote healthy root development and prevent the presence of fungal pathogens
- Provide an environment for root anchorage and development
- Be free of pathogens and weed seeds which could compromise crop growth
- Have a pH near neutral (for virtually all common vegetable and flower crops)
- Be free of excess salts which can create water imbalances and compromise nutrient uptake


Coco Peat


Compost


Peat Moss


Vermiculite


Perlite

RootShield®

TABLE 1. Common soil media components and inputs to promote seedling health. *Photos: Abby Huetter*

Commercial Organic Soil Mix: What to Look For

If purchasing soil mix, look for a quality bagged soil mix at local agriculture suppliers, nurseries, or garden centers. Soil media companies that offer bulk pricing can be found in most agricultural regions. Buying in bulk will be less expensive and use less packaging.

Theoretically, mixes that contain granular fertilizers or compost should meet seedling nutrient needs, but before committing to a specific mix for the season and sowing thousands of seeds into an unknown medium, growers would benefit by first testing out the mix on a smaller scale. Are the granular or compost based nutrients available in the time seedlings will spend in containers? Are there enough available nutrients? Too little? Too many? Is the compost in your mix high quality and providing nutrients when the seedlings need them? Is your compost source immature and potentially inhibiting germination or suppressing growth?

Products labelled "propagation" or "seed starting" mix typically have a lighter, finer texture, are peat moss and/or coco-peat based, and are designed to provide a balance of moisture retention, drainage, and aeration, but these mixes often lack fertility inputs. If your bagged mix does not have adequate fertility supplied via the ingredients, then fertility will need to be provisioned for, either through amending the mix with dry ingredients and/or providing liquid fertility shortly after seedlings have germinated.

For certified organic operations, be sure to check to see if the bagged mix and any added ingredients are certified organic.

SYSTEM EFFICIENCIES: If you are able to purchase a mix containing adequate fertility in loose-fill packaging that does not require any amendments or sifting, you will save considerable time.

Making Your Own: What's Involved?

Due to the time and labor involved in making soil mixes, most growers purchase ready-made mixes. However, if you choose to make your own, you'll need to be familiar with the materials and the cost, how to mix the ingredients, and how to properly store ingredients and your completed soil mix. As with purchased mixes, any mix you make should provide a balance of water retention, drainage, aeration, fertility, a near-neutral pH, and be free of pathogens and weed seed.

Making your own soil mix gives you the ability to more precisely tailor the mix to your needs and crops, but also requires you to have three to five raw ingredients on hand and a place to store them to protect them from the elements. Mixing the materials will require either a fair amount of hand labor or the purchase of a concrete mixer or similar machinery, both of which can be expensive. To create as much efficiency as possible, keep all your raw ingredients stored where you will mix them and store and use your finished product where you will fill your containers.

If using compost as a primary ingredient, exercise caution about the potential for high electrical conductivity (EC)/excess salts and have your compost tested prior to committing it to your mix. Also be aware that a high compost volume can increase water holding capacity but decrease aeration, leading to slower germination and a greater potential for damping off organisms to thrive if water is not managed carefully.

MAKING SOIL MIX

TABLE 2. Hand mixing soil media. Raw ingredients are first laid out in layers. The pile must then be broken apart and reassembled, with water added as needed until all ingredients are homogenized and moisture is adequate to initiate seed germination. *Photos: Abby Huetter*

SOIL MIX ASSAY

The assay and observation template provide guidance in evaluating the quality of soil mixes for seedling propagation, whether purchased or made in-house, so that you are confident that your chosen mix will produce high quality seedlings for transplant.

Of course, growers can send mixes to an analytical lab, but this can be costly and while it can provide precise information about pH and nutrient benchmarks, lab tests typically do not provide additional important information, such as: How well does a mix hold water? How well does water infiltrate? How easy is it to remoisten once it has become dry? Does the surface remain well aerated or does it crust over or become a habitat for surface algae? Observing first-hand how a mix performs in your greenhouse and how select seedlings actually grow is information you can only gather by doing in-house trials.

To perform a simple soil mix trial you will need:

- All potential mixes to trial side by side.
- Containers–ideally the trays you most commonly use, but could just be 6-packs for each crop and soil combination. A larger sample size will provide more information, but will require more soil, seed, bench space and labor to complete the process.
- Seeds of crops that readily show signs of nutrient stress, pH imbalance, and water stress such as broccoli, cress, and wheat. Cucurbits can be particularly useful for assessing the drainage and aeration potential of mixes as they are sensitive to overly wet soils.
- Labels to identify your different samples. It is usually best to use a coding system (ie: Sample 1, 2, 3 or A, B, C) to increase observation objectivity.
- Observation template (casfs.ucsc.edu/about/publications/grower-guides/pdf-downloads/soil-mix-observation-template.xlsx) that records percent germination at 3 and 7 days, and leaf color, plant development observations (canopy and roots) at 7, 14, 21, and 28 days. You may also wish to continue your trials longer than 28 days to get a sense of the holding power your mix has in the event that you are not always able to plant out all crops in a timely manner.

Steps for carrying out an in-house soil mix trial:

1. Assemble enough of all of the mixes you want to trial.
2. Assemble seeds and labels for trial.
3. Fill enough containers to have at least 1 tray, 6-pack, etc. for each crop to be trialed in each potential soil mix. For example, if you're using 200-cell trays, trialing 4 different mixes, and using broccoli, cress, and wheat, then you need at least 12 200-cell trays to carry out the trial.
4. Label each tray with the crop name and code for that particular soil mix.
5. Sow each tray consistently with the same number of seeds at the same depth in each cell and cover uniformly.
6. Place all trays in your greenhouse, germination chamber, or other location you typically use for seed starting, being sure that conditions are as uniform as possible for each trial sample.
7. Water in consistently and continue watering as conditions warrant throughout the entire trial cycle.
8. Using the template provided, collect germination data at 3 and 7 days after sowing, making an initial assessment of the performance of each of your mixes.
9. Use the template to record your observations around plant health/development/vigor for the 7, 14, 21 and 28 day windows, at a minimum. You can observe at more regular intervals if you have the time. At each juncture, also record how each soil mix is performing in terms of moisture retention, drainage, surface crusting, and any other aspect that will be important in future plant performance.
10. From your observations and the data collected on your observation template, make an informed decision about which soil mix is the best choice for your operation and if you will need to amend the mix or make other adjustments to achieve optimal seedling development.

Containers

It is important to use suitable containers for your seedlings, matching cell size with the root nature of the crop, size of desired transplant, appropriate media, available space in the greenhouse, and your ability to get seedlings into the ground in a timely manner. Cell or plug-type trays are the most common containers used to produce seedlings and are available in a wide range of materials, cell sizes, and cell shapes.

Root Nature of Crop

Large-seeded crops like cucurbits and sunflowers tend to have extensive root systems and, if not grown as direct-seeded crops, benefit from being grown in larger cell sizes. Faster growing seedlings usually do very well in smaller cell sizes. The smaller the cell size (for crops that can handle it), the less soil will be required to grow the plant to transplant size and the more efficiently you'll be using greenhouse space and water.

Choosing smaller cell sizes, where appropriate, is more resource efficient as long as you can manage moisture and fertility and get the plants into the ground before becoming root bound. It is important to be aware that smaller cell sizes mean less root run and less available soil fertility, which can lead to crops becoming root bound quickly. Also, smaller cells will dry significantly faster than large cells, thus requiring more frequent irrigation, which can increase labor demand.

Container Materials

Modern containers are most commonly made of one of three materials:

Polystyrene/styrofoam, which typically has a useful lifespan of five to ten years, is lightweight, moderately priced but easily damaged, and is not recyclable.

Polyethylene-HDPE#2/hard durable plastic, which can last 15 years or more, is virtually indestructible but heavier to transport, usually higher priced than other materials, and is recyclable.

FIGURE 2. Polystyrene/Styrofoam trays-showing 334, 200, and 72 cell trays with a 13x26 footprint.

FIGURE 3. Polypropylene-PP#5/lightweight plastic trays-showing strip cells, 200 and 512 cell trays with a 10x20 footprint.

FIGURE 4. Polyethylene/Heavy Duty trays-showing 242 and 162 cell trays with a 13x26 footprint.

FIGURE 5. Traditional wooden flats (12x18 and 12x24 footprints pictured) can be any dimension you desire and are used for broadcasting high density sowings such as leeks and onions. *Photos: Christof Bernau*

Polypropylene-PP#5/lightweight plastic, which can last up to five years, is somewhat flimsy and may require a separate tray for carrying, and is recyclable.

Visit **casfs.ucsc.edu/about/publications/grower-guides/pdf-downloads/containerchart.pdf** to learn more about the advantages and disadvantages of each container option.

SYSTEM EFFICIENCIES: Despite the myriad range of cell sizes and shapes available, modern propagation trays are principally available in either 1020 (10"x20") or 1326 (13"x26") formats. Use trays with the same size "footprint" (length x width) to maximize space utilization on greenhouse tables. Also, limiting the number of cell sizes you use can simplify "blocking" for proper water delivery and make it cost effective to use a vacuum seeder to speed up seed sowing. See the following sections for more information.

FIGURE 6. Inconsistent footprints, use of bench space not optimized.

FIGURE 7. Uniform footprint, good use of bench space.
Photos: Abby Huetter

FIGURE 8. Blocking seedlings by life stage is helpful in ensuring your seedlings get the proper amount of water. See the "Irrigation" section of this guide for more information.

FIGURE 9. Extreme uniform footprint at a large scale transplant nursery.
Photos: Christof Bernau

Seeding

Consider the benefits of sowing with a vacuum seeder versus seeding by hand. Although somewhat expensive, a vacuum seeder sows crops very quickly and will save time and labor costs, paying for itself after a couple of seasons. Vacuum seeders are especially useful when sowing round seed crops, such as alliums and brassicas, and pelleted seeds, but are less efficient when sowing flat, oblong seeds such as those of cucumbers and tomatoes.

FIGURE 10. Hand sowing into open flats.

FIGURE 11. Sowing with cardstock to regulate seed drop.

FIGURE 12. Hand sowing with plastic seed sower to regulate seed drop. *Photos: Abby Huetter*

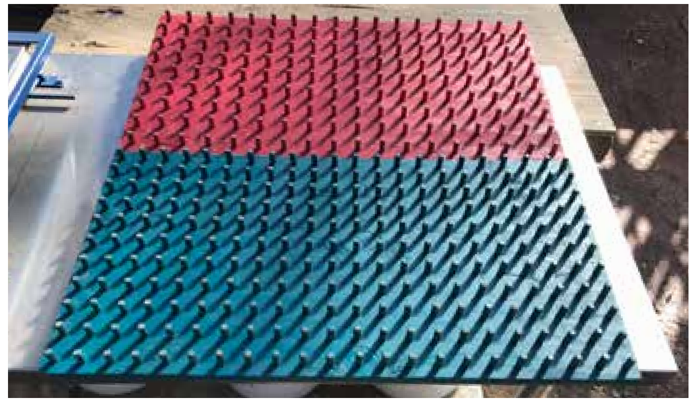


FIGURE 13. DIY dibblers for 162 and 242 cell trays.

FIGURE 14. DIY dibblers, top view. *Photos: Christof Bernau*

It is important to note that a vacuum seeder will require a set of individual seed plates that must be sized and drilled to precisely match the containers you use, thus requiring you to have uniform tray size and cell configuration to gain the benefits that vacuum seeders can provide.

SYSTEM EFFICIENCIES: Consider building or purchasing a dibbler board to save time spent sowing seeds. These boards have dowels attached to create depressions in the soil mix in every cell of a seedling tray. Make sure your dibbler board has the same footprint as your trays and that each dowel is in the correct place to make a depression in the center of each cell.

Time Studies at the UCSC Farm

Through time trials conducted at the UCSC Farm, we have found that sowing with a vacuum seeder is most effective for use with crops that have round or pelleted seeds, but with practice vacuum seeders reduce labor inputs on the vast majority of seedling crops. Though pelleted seeds are more expensive than non-pelleted seeds, when available, the time savings is certain to make the investment worth it. Visit **casfs.ucsc.edu/about/publications/grower-guides/pdf-downloads/seedling-trials.pdf** to view the results of our time studies of seeding, irrigation, and making soil mix.

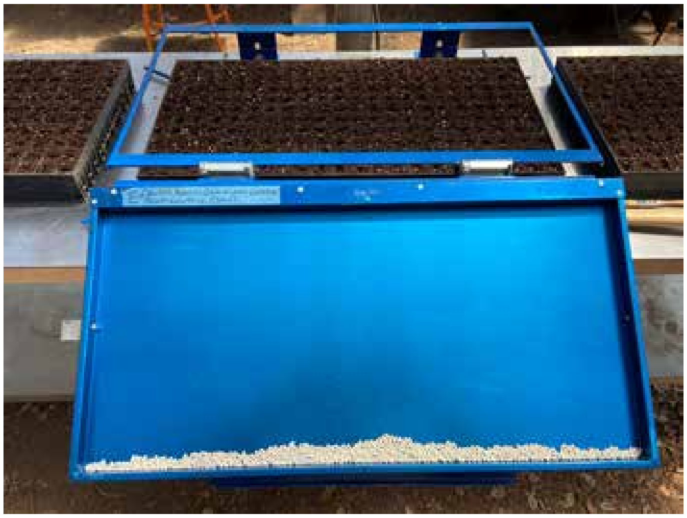


FIGURE 15. Vacuum seeder seed plate with loose pelleted lettuce seed before distribution to each seed hole.

FIGURE 16. Vacuum seeder in operation with pelleted lettuce seed held in place and ready to drop into the tray.

FIGURE 17. Pelleted lettuce seed just sown using vacuum seeder into pre-dibbled 242 tray.

FIGURE 18. Brushes and mallet to clean vacuum seeder, eliminate doubling, and sweep seed to fill gaps on seed plate. *Photos: Christof Bernau*

METHOD	EFFICIENCY	COST
Hand seeding	Least efficient; requires significant time and labor, especially when sowing very small seeds	No upfront costs other than labor
Hand-built vacuum seeder	Extremely efficient, especially with round and pelleted seeds	$100
Off the shelf, general-use vacuum seeder	Extremely efficient, especially round and pelleted seeds	Off the shelf vacuum seeders are priced in the $800-$2,500 range, depending on features and usually require the purchase of individual seed plates that work with specific seed types. Individual seed plates can cost $75-$300 each for all available seeders.

Irrigation

Knowing when and how much to irrigate is key when producing healthy seedlings. Delivering too much water or watering too frequently can lead to losses due to damping off and/or stunted seedlings due to lack of available oxygen in the soil media. Not consistently providing water during germination can lead to poor germination results. Not watering deeply enough once plants have germinated can limit subsequent seedling growth if plants cannot access the necessary water and nutrients that support healthy development.

Delivering the right amount of water with the appropriate frequency, in conjunction with good quality soil media and appropriate environmental management, will lead to strong germination and seedling development. See eGro's "Art and Science of Watering Greenhouse Crops" (e-gro.org/pdf/2017_721.pdf) for more information on irrigating your seedlings.

FIGURE 19. Soil moisture sequence, from left to right: 1. Very dry seedling 2. Seedling with surface dry down and some moisture still remaining at bottom of cell 3. A "watered" seedling that still needs more water to supply entire root zone 4. A well watered seedling with moisture available throughout the root zone. *Photo: Christof Bernau*

FIGURE 20. Hand watering with a wand and "water breaker." *Photos: Carolyn Lagattuta*

Manual irrigation

Hand delivery requires the lowest amount of capital investment when it comes to irrigating. One only needs a water source, hoses, an inline shut off valve, a wand, and water breaker or similar small droplet watering nozzle. Drawbacks to hand watering include the time and labor involved and the potential for uneven plant performance, unless water is being delivered by a highly skilled irrigator.

SYSTEM EFFICIENCIES: If using a hand delivery system, consider installing an overhead Hi Hose "trolley" for moving hoses efficiently along the length of the greenhouse. The Hi Hose system reduces operator fatigue, eliminates hoses catching on table legs, kinking and pressure loss, and improves sanitation by keeping your water source off of the ground.

FIGURE 21. Hi Hose coiled.

Hi Hose extended. *Photos: Christof Bernau*

Overhead Delivery Via Semi-Automated and Automated Sprinkler Systems

A well-designed sprinkler system can uniformly deliver water to an entire crop with very little time or labor required.

In **semi-automated systems**, water delivery and shut off are provided by a mechanical controller and a built-in overhead sprinkler system. The grower must assess irrigation needs depending on factors like prevailing weather conditions, crop life stage, and cell size/soil volume, and then program an irrigation controller to deliver the appropriate volume of water and frequency of delivery. This type of system can provide highly uniform water delivery and save a tremendous amount of labor. However, when weather conditions change, or crop development needs shift, growers must re-program controllers or change schedules to match new demands and conditions.

In **fully automated systems,** environmental sensors, tied to weather forecasting information and grower-determined set points, work in concert with computer programs to respond to current environmental conditions and optimally meet the needs of developing seedlings. While much more costly to set up, well-designed automated systems typically have a rapid return on investment by virtue of providing immense labor savings and greatly improved crop quality and consistency.

Despite the many benefits of semi- and fully automated systems, one important caveat to be aware of is that plants at the edges of benches and blocks will tend to dry out faster than those in the interior, requiring some follow-up hand watering. Even with this limitation, the labor savings offered by automated systems is immense and can pay for the cost of investment in a single season. When designing a semi-automated system, it's important to make sure you have full coverage of your tables, including corners and edges, in order to minimize the amount of time you spend on spot watering or touch up watering.

SYSTEM EFFICIENCIES: "Blocking" trays is a method of organizing plants at similar life stages and similar needs together in separate zones so that each zone can be managed to meet the needs of the crops in that block. For example, all recently-sown and ungerminated trays should be blocked together, recently-germinated but still young crops should be blocked together, and maturing seedlings should be blocked together, thus allowing your irrigation system or hand waterer to cater specifically to the needs of the crops within each block.

FIGURE 22. Typical low-cost irrigation controller capable of running multiple schedules programmed to meet different crop needs. *Photo: Christof Bernau*

FIGURE 23. Typical 3/4" solenoid valves with screen filters to prevent debris from clogging sprinkler nozzles. Three bench, three valve layout, controller in right rear of photo, valves for each station in left rear of photo and sprinkler nozzles arrayed evenly over each bench to provide uniform water delivery. *Photos: Christof Bernau*

Greenhouse Irrigation Concepts and Terms

Saturation: Saturation in containers occurs when irrigation water fills all of the pore space in the soil medium. In high quality mixes this is only a very temporary state and excess moisture quickly drains from the mix.

Wet/Dry Swing: Manage container soil so that it is not continually saturated, thus depriving roots of necessary oxygen. By facilitating a wet/dry swing, pore space modulates or fluctuates back and forth between being filled with oxygen and water, giving roots access to both of these critical elements.

Container Capacity: Similar to field capacity, container capacity occurs when excess water has drained, air has returned to part of the pore space, and maximum water is held in the pore spaces against the forces of gravity.

Percent Container Capacity: Describes the relative availability of water in the mix as water is lost to uptake by the plant roots and evaporation.

Perched Water Table: Describes the water that is held at the bottom of flat-bottomed containers. This condition may be detrimental to plant health if the soil mix does not contain an adequate amount of coarse materials to promote good aeration throughout the root zone.

Percent Surface Dry Down: Applies specifically to the germination phase of seedling production when frequent but small quantities of water must be delivered to facilitate germination and prevent newly emerging roots from drying out.

- For the vast majority of seed-grown crops, a small quantity of water should be re-applied when 30–50% of the visible soil surface has dried down.
- For larger-seeded crops such as sunflowers and members of the cucurbit family, growers typically allow 100% of the surface soil to dry down before re-applying moisture.

Supplemental Fertility

Although organic mixes ideally contain all the fertility needed to sustain steady, uninterrupted plant growth, additional readily-available soluble inputs are sometimes necessary. Supplemental fertility is the practice of providing seedlings with additional nutrients that may be lacking in your soil mix. Commonly, these nutrients are blended into water and delivered through irrigation rather than as a primary ingredient in soil mix, but they can also be supplied as granular input in or on top of the soil medium.

Supplemental fertility can compensate for poor quality, nutrient-deficient ingredients, especially immature or older, poorly-stored compost, and to alleviate stress, especially in cell-type containers when plants are past their optimal transplant stage, have become root bound, or are showing signs that previously available nutrients have been exhausted. Supplemental fertility can also be used to stimulate growth, such as when the grower needs to accelerate plant growth for a specific plant-out date or when seedlings have been contracted for sale and it is clear that they will not reach salable size quickly enough.

Supplemental fertility can promote biological activity and nutrient release by supplying nitrogen to the soil microbial population which uses the supplemental nitrogen to facilitate the release of plant-based nutrients from the soil mix. If cool conditions prevent the soil microbes from mineralizing soil-based granular nutrients, then soluble nutrients can support strong growth.

Certain crops are more likely to need supplemental fertility than others, especially if they will linger before being transplanted to the field. These crops include peppers, celery, alliums, and brassicas.

Signs That Fertility is Lacking

One obvious indicator that seedlings are deteriorating due to lack of fertility is the change in color from a plant's primary color (often green) to a paler, softer color (such as yellow). Cotyledons may also begin to lose color, indicating that their offerings have diminished. Roots that have filled the entire root run and have begun to spiral and become root bound is another sign that a seedling could benefit from supplemental fertility.

FIGURE 24. Stock flower seedlings showing discoloration and need for supplemental fertility. They are also "stretching," indicating they will flower soon and probably aren't worth fertilizing and planting out.

FIGURE 25. Kale seedlings showing discoloration, lack of available nutrients and in need of soluble fertility to bounce back. *Photos: Abby Huetter*

Application Methods

Supplemental fertility can be applied in a number of ways, including:

Blending inputs into soil mixes at the time of mix making

This common strategy requires prior knowledge of the need for additional fertility and is most useful with fast- to medium-acting meals and powdered ingredients.

"Top dressing" with powdered, granular, or pelletized ingredients on the surface of container soils

This method can be effective with fast- to medium-acting inputs, depending on the crop life cycle and extent of immediate need.

Applying water-soluble inputs as a soil drench as part of a regular irrigation set ("fertigation")

This is a particularly useful, quick-fix approach to address immediate nutrient deficiencies or to rapidly increase the rate of plant growth using readily available, water-soluble nutrients delivered with irrigation directly to the root zone.

Delivering water-soluble nutrients as foliar sprays

The spray should be directed at the leaf undersides where stomata are concentrated to maximize uptake potential. Follow label instructions carefully, as fish based products, when delivered in excessively high concentrations, can burn foliage.

Materials That Provide Supplemental Fertility

Most products that can provide supplemental fertility are based on extract or fermentation of fish byproducts. Hydrolyzed plant proteins are also available and can be another good source of soluble nutrients. Other options include compost tea, worm casting leachate, or kelp powder. Visit **casfs.ucsc.edu/about/publications/grower-guides/pdf-downloads/supplemetalfertility.pdf for more information on these materials**.

Sustainability Considerations

While the plant extract inputs are fairly sustainable, the sustainability of fish products depends on whether the product is made using primary catch, bycatch or processing waste fish products. Products made from processing waste and bycatch are preferable since these resources would otherwise be disposed of.

Another consideration is the potential for growers to rely too heavily on highly soluble nutrient inputs, which mimics the conventional mindset of feeding plants directly with readily available ingredients rather than building soil health and biology to promote nutrient release and pathogen resistance.

Dosages

Follow the instructions on the product label to determine the dosage of a supplemental input. Frequency of delivery is also important to consider and depends on the nature of your soil mix. If the mix already has sufficient fertility and you are providing additional nutrients, then one application per week should suffice. If the soil mix provides no nutrients, provide supplemental fertility daily or every other day.

With daily application of liquid fish products, salts could be an issue and can manifest as browning leaf tips, drop off of lower leaves, and blackened root ends. Monitoring for soil electrical conductivity (EC) in your run-off can confirm the presence of excess salts and the potential need to lower the frequency or strength of your liquid fish applications. For more information on measuring pH and EC, see North Carolina State University Horticultural Substrates Lab's step-by-step procedure for measuring pH and soluble salts in greenhouse crops using the PourThru method of soil solution extraction (projects.ncsu.edu/project/hortsublab/pourthru/M_M.htm) and eGro's "PourThru" video (youtube.com/watch?v=wyKIxk-YNQA).

Tools for Delivery of Liquid Inputs

In smaller scale operations, supplemental fertility may be delivered through a watering can or backpack sprayer. If you'll be relying more consistently on liquid fertility, purchase a fertilizer injector that allows blending directly into hose water or into the overhead spray system. These tools can be easily calibrated to the desired dilution rate. Be aware that viscous material tends to accumulate at the bottom of the container and can clog your irrigation nozzles; this buildup can be remedied by stirring the ingredients with a cordless drill with a long-handled paddle attached or adding a disc filter into your delivery system.

Potential Concerns

Potential concerns of adding supplemental fertility include the high cost of inputs and equipment and the increased time and labor spent mixing materials and application. Investing in a fertilizer injector and proper filtration creates an upfront cost, but can pay for itself quickly due to the immense labor savings of delivering nutrients continuously through a hose, or better yet, through an existing overhead irrigation system, rather than by hand.

There are also environmental concerns associated with supplemental fertility. Water soluble nutrients, such as nitrogen in fish emulsion, can easily be leached out of growing containers and potentially enter local waterways if irrigation is poorly managed and vegetative buffer strips are not present to preserve water quality. Excess nitrogen application can also promote highly nitrogenous, pest-susceptible growth, which may then lead to using more inputs to control pests.

FIGURE 26. Fertilizer injector on mobile dolly with cam-lock fittings so it can be easily connected/disconnected and moved from greenhouse to field and back. *Photo: Christof Bernau*

Transplant Readiness and "Holding" Transplants

Before transplanting your seedlings, make sure they're fully developed and prepared for the change. If you must hold transplants past the point of optimal development, it's important to utilize the correct "holding" strategies to keep your seedlings in good condition.

Qualities of Transplant-Ready Seedlings

Recognizing the characteristics of a mature seedling is a skill easily developed with a small amount of time and experience. Seedlings ready for transplant should ideally have a root system and root knit sufficient to hold together soil surrounding the roots, and at least two sets of well-developed true leaves that are true to color for the species.

Be sure to "harden off" your seedlings before planting them outdoors. Hardening off is the process of transitioning mature seedlings from "controlled" greenhouse conditions to outdoor growing conditions. Seedlings should experience full exposure to day/night temperature fluctuations to help build carbohydrate reserves, and full exposure to the wind and sun to strengthen cell walls and enhance tolerance to future extremes in growing conditions. The greater the difference between your "controlled" greenhouse conditions and outdoor growing conditions, the more important it is to thoroughly harden off your seedlings, especially early in the season when day/night temperature fluctuations are often greater than later in the year, or if there is potential for frost damage.

"Holding" Transplants

At times, it may not be possible to transplant seedlings when they are at their optimal stage of development. This could occur:

- When excessive rains prevent cultivating and preparing the soil
- When inadequate rain means it's too dry to prepare the soil without degrading soil structure and you must wait for rain or pre-irrigate
- In cases of relay planting, when the ground for your new seedlings is still occupied by a crop that has not yet matured
- When you can't prioritize new plantings due to other seasonal demands or you can't align labor with the prime planting time

It is important to know which crops will tolerate holding and delays in planting and which will not. For those that do not hold well, prioritize their planting whenever possible. Cucurbits, heading brassicas, bulbing onions, and peppers, for example, typically do not respond well to holding. Leeks, tomatoes, collards, and kale are all crops that can tolerate being held and will rebound once transplanted.

"Holding" Strategies

To keep your plants in good condition until you are ready to transplant, you can provide supplemental fertility to compensate for the nutrients that may no longer be available in your soil mix. Another option would be to move seedlings to a cooler location (outdoors from a greenhouse or a cooler spot if already outside) to slow the rate of growth. You can also move seedlings to partial shade to reduce photosynthesis and slow growth, though this should only be done in partial or part day shade as excess shade will cause plants to stretch and become leggy. If they are held in shade for an extended period of time, plants may need to be hardened off again to transition them to garden and field conditions.

Another strategy is to transplant seedlings into larger cell sizes to provide them access to additional root run and nutrients to continue steady and uninterrupted growth. This process requires substantial labor, additional soil mix, and added bench space to hold seedlings that are now in lower density trays, and may only be practical for very small scale operations.

These strategies can keep your plants healthier when plant out is delayed. However, if you see signs of bolting, premature stretching, or excessive root crowding in your seedlings, they may not be worth planting out.

FIGURE 27. From left to right: 1.Young kale, roots not yet holding/knitting root ball 2. Well-developed canopy and good root knit—just ready for transplant 3. Slightly past peak seedling—starting to show some nutrient and crowding stress.

FIGURE 28. 1. Cotyledon stage but roots are well developed 2. True leaves emerging, roots already knitting root ball 3. Full canopy, well-developed root system—ready for transplant 4. Seedling showing stress: Canopy discoloration, flower buds present, roots crowded—all signs that plants are past their prime. *Photos: Christof Bernau*

Pest and Disease Management

Pest and disease management in the greenhouse starts with prevention and good cultural practices, and is reinforced by monitoring and early detection to limit potential problems before they spread. This section covers steps you can take to prevent or minimize pest and disease problems. You can speak with local growers, Cooperative Extension agents, and IPM practitioners to find out what specific problems to anticipate in your region, which crops may be most vulnerable, the potential severity of particular pests and pathogens, and the times of year to be especially vigilant.

Prevention

Sanitation: Greenhouse structures, greenhouse floors, benches, propagation containers, hand tools, hoses, etc. can all harbor plant pathogens. Good sanitation programs should include periodic cleaning or disinfecting of all materials and facilities to prevent contamination.

Other important sanitary practices include using only pathogen-free soil media, imported seed, and plant material, cleaning all surfaces where you handle seed and young seedlings, removing/culling infected plant material as soon as possible to prevent the spread of pests and pathogens, and keeping hoses, especially hose ends, up and off of the floor.

Propagation Media: Propagation media is a potential source of contamination, especially for soil borne bacteria and fungi, as well as weed seeds. In order to minimize these risks, use sterile, soilless media or use biologically active, disease-suppressing media based on high quality composts, and/or inoculated with beneficial fungi or mycorrhizae.

Even with sterile media, it can be helpful to add beneficial fungi into a soil mix to reduce fungal pathogen damage. At the UCSC Farm, we use a product called RootShield® G, a granular input that contains the beneficial fungus *Trichoderma harzianum* T-22. The *Trichoderma* fungi attach to roots, providing a buffer and direct competitor against pathogens, such as damping off fungi, that can cause substantial losses in overly wet and poorly drained soil media. This addition alone will not eliminate fungal pathogens, but is a useful tool, combined with your cultural practices, to improve seedling health.

Seed: Seeds and plant stock can also be a source of contamination. You can protect against this potential by using seed and seedling material that come from reliable sources and are certified to be pest- and disease-free. Using seed pre-treatment techniques, such as hot water baths, to kill fungi and other pathogens can also prevent contamination. Isolating and observing any imported plant material prior to bringing this new material into the greenhouse is another effective method of limiting the potential for pathogen introduction.

Exclusion: Excluding pests from the greenhouse will also help prevent problems and, depending on your location, may be a critical tool in maintaining a pest-free growing environment.

- Screen all points of entry into the greenhouse, including vents, fans, and doorways
- Use floating row covers over cell trays to keep flying insect pests off of emerging crops
- Use physical barriers, such as water basins or sticky resins on table legs, to prevent ants and other crawling insects from having access to young crops

Cultural Practices

Good cultural practices across the entire life cycle of your seedling crops are fundamental to effective pest and disease management. In addition to environmental management, good practices can include selecting pest- and disease-resistant varieties, avoiding crops vulnerable to known problems, and growing crops at appropriate seasonal junctures where environmental conditions naturally facilitate healthy, vigorous, pest- and disease-resistant growth.

Central to the process of preventing pests and diseases and promoting vigorous, uninterrupted growth is careful management of environmental conditions in the greenhouse. This includes managing:

Temperature: The complex of fungi that cause "damping off" damage thrive when soils are constantly moist and temperatures are steadily in the 68°F to 86°F range. While this range is both ideal for damping off organisms and for healthy growth of many common crops, damping off damage can be limited by using well aerated soil media and sacrificing optimal growing temperatures by cooling below the range that damping off fungi favors.

Moisture: Constantly wet soil deprives roots of necessary oxygen, limits the mobilization of organic nutrients in the soil mix, and can create conditions ideal for damping off fungi. Excess irrigation can also lead to nutrient leaching from the soil media, depriving crops of valuable resources and potentially compromising local surface or groundwater. Overwatering is one of the most common problems in greenhouses and should be relatively easy to correct. Ensuring an adequate wet/dry swing in the soil media post-germination is critical to seedling health.

FIGURE 29. Cilantro infected with the damping off fungus *Pythium*, showing characteristic root loss and shrunken stem diameter.

FIGURE 30. Swiss Chard infected with the damping off fungus *Rhizoctonia*, showing characteristic stem collapse at the soil surface, adjacent to healthy seedlings. *Photos: Steve Koike, TriCal Diagnostics*

Air circulation: Consistent air circulation, even when all vents are closed, promotes strong cell wall formation, helps regulate greenhouse temperatures and creates an environment far less favorable for fungal pathogens.

Fertility: In concert with other cultural practices, adequate (but not excessive) soil fertility promotes healthy, uninterrupted growth. Excess fertility can lead to lush, rangy growth and attract aphids and other insects that feed on nitrogen rich crops (see "Soil Mixes" section of this guide).

Monitoring and Early Detection

Ideal management also includes monitoring and early detection of pest and disease problems to minimize crop loss and the need for more extensive intervention.

An important first step is to monitor all growing areas consistently throughout the growing season. Close observations and looking for early signs of disease and pest presence will provide the ability to respond by changing cultural practices or using intervention tools in a timely manner.

If you suspect pest and/or disease problems, use identification tools and reference the publications and websites listed in the "Additional Resources" section. Purchase and know how to use a 10X or stronger hand lens to identify pests in question. You can use yellow or blue sticky traps to sample for and partially control flying insects such as whiteflies, shore flies, and fungus gnats. Knowing what pests you are encountering and in what concentrations will allow for informed decision making to control issues early.

Establish clear tolerance thresholds to initiate control actions when shifts in cultural practices and environmental management do not provide adequate controls. Rogue (cull) or quarantine infected crops to prevent the spread of problems to nearby crops susceptible to the same pests or diseases. Roguing requires sacrificing some for the good of the whole. Quarantining allows treatment strategies to be applied selectively and in isolation from other susceptible crops, thus reducing the likelihood of more widespread outbreaks.

The example below provides a framework for managing fungus gnats, a pest common to Central California growers. Visit **casfs.ucsc.edu/about/publications/grower-guides/pdf-downloads/pestchart.pdf** to view tables for other managing other common pests including damping off fungi, aphids, whiteflies, and rats.

FIGURE 31. Shore Fly.
Photo: James Bailey

FIGURE 32. Fungus Gnat.
Photo: Richard Leung

Example pest management table

Pest	Fungus gnats
Causes	• Attracted to soil mix or a media environment with a very large presence of peat moss and/or only partially decomposed organic matter. • Tend to favor consistently wet soil environments and soil media that does not drain well.
Type of damage	• Adults lay eggs in soil media and once the eggs hatch, the larvae feed on roots, causing substantial below-ground damage, stunting, clorosis, sudden wilting, and greatly weakened crop development.
Prevention measures	• Keeping yellow sticky cards present in the greenhouse throughout the growing season can be helpful in identifying the presence of fungus gnats, as opposed to shore flies which are attracted by similar soil and environmental conditions but do not cause measurable damage. Yellow sticky cards, combined with a hand lens, are valuable tools in identifying fungus gnats, which have similar morphology to mosquitos, versus shore flies, which look like flies. These traps will capture some fungus gnats amongst your crops, but will not provide full control. Rather, they will provide you information you need to begin intervening. • Limit the amount of undecomposed organic matter in soil and time watering to allow for thorough wet/dry swings.
Tolerance threshold	• Very low
Treatment	• Gnatrol: a strain of Bt that preys on fungus gnat larvae, interrupting root feeding and reproduction. • NemAttack: a beneficial nematode, *Steinernema feltiae,* that parasitizes fungus gnat larvae, interrupting root feeding and reproduction.
Crops most susceptible	• Virtually all crops started in the greenhouse are susceptible if your mix and watering practices create a favorable environment for fungus gnats.

Treatment/Intervention

As a last resort, use organically acceptable chemical controls or biological control agents that specifically and selectively target the pest or disease problem you are trying to manage. Following as many as possible of the above strategies and intervening early can greatly reduce losses and increase the efficacy of the inputs organic growers have at their disposal.

When preventing and managing specific pests, it helps to create a framework for recognizing the pest and determining which steps to take to treat and prevent further damage. Your framework should include the factors that contribute to the presence of your pest, the type of damage it causes, prevention measures, tolerance threshold of your crops, how to treat the damage and/or remove your pest, and which crops are most susceptible (see example on previous page).

FIGURE 33. Yellow sticky traps attached to plastic flats and placed at soil or canopy level amongst vulnerable crops will greatly aid monitoring. *Photo: Abby Huetter*

FIGURE 34. Close up of yellow sticky traps. *Photo: Christof Bernau*

ADDITIONAL RESOURCES

Ball Redbook: Greenhouses and Equipment, by Chris Beytes and Jim Nau. Ball Publishing, 2011.

Garden Insects of North America: The Ultimate Guide to Backyard Bugs, by Whitney Cranshaw and David Shetlar. Princeton University, 2017.

Greenhouse BMP Manual, compiled by Tina Smith and Paul Lopes. University of Massachusetts Extension, 2010. ag.umass.edu/sites/ag.umass.edu/files/book/pdf/greenhousebmpfb.pdf

Greenhouse Crops and Floriculture Program Fact Sheets. University of Massachusetts Extension. extension.umass.edu/floriculture/fact-sheets/organic-greenhouse-production-and-resources

Greenhouse IPM: Sustainable Aphid Control, by Lane Greer. ATTRA, 2000. attra.ncat.org/product/greenhouse-ipm-sustainable-aphid-control

Greenhouse IPM: Sustainable Thrips Control, by Lane Greer and Steve Diver. ATTRA, 2000. attra.ncat.org/product/greenhouse-ipm-sustainable-thrips-control

Greenhouse IPM: Sustainable Whitefly Control, by Lane Greer. ATTRA, 2000. attra.ncat.org/product/greenhouse-ipm-sustainable-whitefly-control

Integrated Pest Management. UC Davis. www.ipm.ucdavis.edu

Integrated Pest Management for Bedding Plants: A Scouting and Pest Management Guide. New York State IPM Program publication 407, 1999. https://ecommons.cornell.edu/bitstream/handle/1813/42426/ipm-bedding-plants-NYSIPM.pdf?sequence=1

Integrated Pest Management for Floriculture and Nurseries, by Steve Dreistadt. University of California Agriculture and Natural Resources publication 3402, 2001. ipm.ucanr.edu/IPMPROJECT/ADS/manual_floriculture.html

Integrated Pest Management for Greenhouse Crops, by Lane Greer and Steve Diver. ATTRA. attra.ncat.org/product/integrated-pest-management-for-greenhouse-crops

Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide, by Mary Louise Flint. University of California Agriculture and Natural Resources, publication 3332, 2018.

Plug and Transplant Production for Organic Systems, by Lane Greer and Katherine L. Adam. ATTRA, 2005. attra.ncat.org/product/plug-and-transplant-production-for-organic-systems

Plug and Transplant Production: A Grower's Guide, by Roger C. Styer and David S. Koranski. Ball Publishing, 1997.

Potting Mixes for Certified Organic Production, by George Kuepper, Kevin Everett, and Luke Freeman. ATTRA, 2018. attra.ncat.org/product/potting-mixes-for-certified-organic-production/

Resource Guide for Organic Insect and Disease Management, by Brian Caldwell, Eric Seaman, Anthony Shelton, and Christine Smart. Cornell University, 2013. web.pppmb.cals.cornell.edu/resourceguide

Sustainable Small-Scale Nursery Production, by Steve Diver, Lane Greer, and Katherine L. Adam. ATTRA, 2008. attra.ncat.org/product/sustainable-small-scale-nursery-production

Teaching Organic Farming and Gardening: Resources for Instructors, edited by Martha Brown, Jan Perez, and Albie Miles. 2015. See Unit 1.3: Propagation, Greenhouse Management for details on greenhouse management. casfs.ucsc.edu/about/publications/Teaching-Organic-Farming

Organic and Sustainable Seedling Production: A Guide for Specialty Crop Growers by Christof Bernau and Kellee Matsuhita-Tseng, with contributions from Peter Shaw. Edited by Martha Brown and Erin Foley.

This information was developed for specialty crop growers and is based on practices used at the UCSC Farm. CASFS is a research, education, and public service program at UC Santa Cruz. Learn more at casfs.ucsc.edu, (831) 459-3240. Additional Grower Guides are available online at casfs.ucsc.edu/about/publications.

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