Chapter 8
Weed Management

Lauren Kolb

Weeds are endemic to agricultural fields, as periodic soil disturbances and ample resources favor their growth, proliferation and spread in cropping systems. While weeds perform an important ecosystem function such as preventing erosion and N leaching, and providing food for living organisms, they also compete with crops for resources, resulting in yield and quality losses. The extent to which weeds will dominate the flora of a field is dependent on the size of the weed seedbank, how competitive the crop is in the field, and the ease and practicality of removing weeds once they have emerged. Unlike other pests, weeds are not in the most literal sense, host-specific. Specifically, weeds will emerge no matter what type of vegetable is planted in the field. This is not surprising as the evolution of annual weeds is dependent on predictable patterns of disturbance in annual cropping systems (Vengris, 1953). Further, due to their small seed size, slow growth, and poor canopy development, vegetables, as a group, do not compete well with weeds (van Heemst, 1985). In many vegetable systems, excessive weed competition can cause unmarketable crop stands, especially non-competitive root crops such as carrots and garlic, and salad greens.

Unfortunately, it is highly unlikely that organic producers will ever have the ability to completely eradicate weeds from their farms, though organic growers need only look to their conventional counterparts to see how ubiquitous and indomitable weeds are. Even with the heavy use of chemical herbicides since the 1940's, weeds are still problematic on conventional farms. However, through thoughtful management practices that take in consideration the ecology of crops and weeds, growers can reduce the production and spread of weed propagules. This will hopefully, *over time*, reduce competition between the crop and weed and subsequently reduce yield and pecuniary loss due to weeds to an acceptable level.

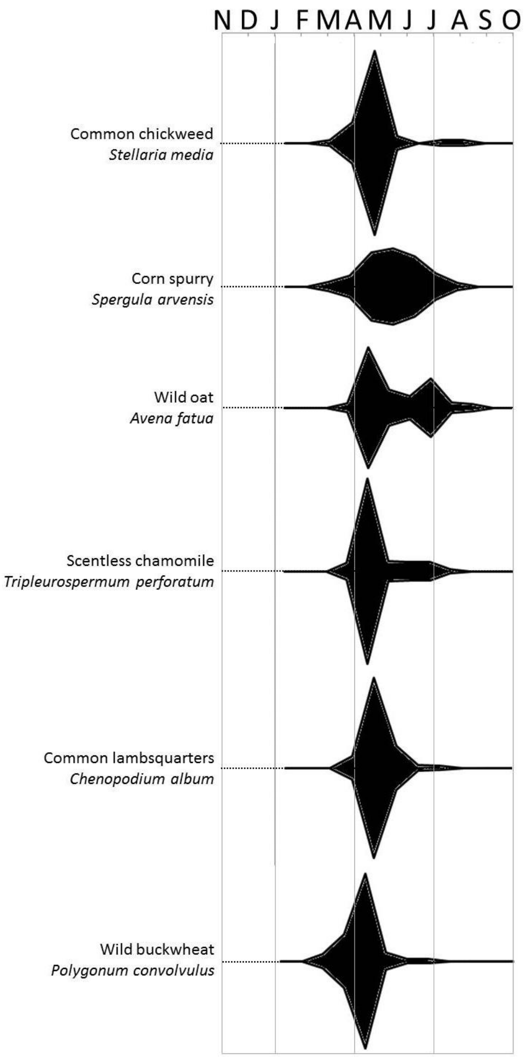
Characteristics of Weeds

A weed is classically defined as a plant out of place, which is why some growers seek to eradicate weeds such as common lambsquarters (*Chenopodium album* L.) and common purslane (*Portulaca oleraceae* L.), while others consider these "crops" and encourage their growth for use in salad mixes. Weeds have evolved to flourish in agricultural systems, as these highly disturbed environments provide repeated opportunities for the selection of weed species best suited to a particular practice or crop (Aldrich, 1984). Characteristics that make weeds competitive in agricultural systems include their i) ability to grow in many different environments, ii) rapid early growth, iii) precociousness (the capability to reproduce quickly), iv) self-compatibility, v) high seed production, and vi) seed dormancy (Baker, 1974). For example, hairy galinsoga (*Galinsoga ciliata* L., Fig. 1), a common weed in organic vegetable production, can flower within 24 days of germination and produce more than 7,500 seeds per plant within eight weeks of germination (Ivany and Sweet, 1973).

Figure 1. Hairy galinsoga, a quick maturing annual weed. Photo courtesy of P.B. Trewatha, Missouri State University

Weeds can be categorized by their lifecycles: annuals, biennials, and perennials. Annual weeds, as suggested by the name, establish, grow, reproduce, and die within one season. These are typically the predominant weed type that vegetable growers encounter. Annual weeds can be separated further into two categories: winter annuals and summer annuals. Winter annuals germinate in the late summer/early fall, remain dormant through the winter, and resume growth in the spring, producing viable weed progeny in late spring/early summer. These weeds will be most competitive with early vegetable crops, like peas, carrots, and *Brassicas*, while also serving as an alternate host for insect pests (Norris and Kogan, 2005) and diseases (Groves *et al.*, 2001). In contrast, summer annuals complete their lifecycle within a growing season, establishing in late spring/early summer and shedding seed in late summer/early fall. These weeds will be most competitive with warm season vegetables such as tomatoes, melons, and corn.

In the Mid-Atlantic region, perennial weeds are generally less problematic then annual weeds in annual vegetable crops, as field preparation and cultivation disrupts the spread of many perennial species. However, if fields are infested with large populations of perennial weeds, efforts to reduce their populations should be attempted before planting annual and perennial vegetables. This can be done through repeated tillage aimed at moving the vegetative propagules (tubers or rhizomes) to the soil surface for desiccation and depletion of food reserves below the soil surface, causing death. The frequency and duration of tillage required to accomplish control depends on the species. For field bindweed (*Convolvulus arvensis* L.), intervals of two to three weeks are recommended (Timmons and Bruns, 1951), while control of quackgrass (*Elymus repens* L.) necessitates cultivation intervals of ten to fourteen days (Bylterud, 1965). Perennial weeds may also be managed with a combination of mowing and cover cropping (Graglia *et al.*, 2006). Though this method does not fully eliminate perennials, it is less damaging to soil health (Teasdale *et al.*, 2007). Because both mowing and including a fallow period precludes the planting of a cash crop, this emphasizes the importance of prevention of establishment of perennials, as they are difficult to manage once they are established in a field.



Identification Figure 2. Seasonal emergence patterns for several common weeds. After Håkansson (1983)

Identifying weeds is the first step in developing a strategy to manage them. Identification allows growers to seek out more information about what practices should be employed to best address that particular weed. A grower would not attempt to control an insect or disease pest without first identifying the pest; the same should hold true for weed pests. As weeds can have different lifecycles, different methods of reproduction, and vary in terms of peak emergence (Fig. 2), it is important to know what weeds are dominant in the field in order to plan rotation schemes, crop planting and tillage dates so as to avoid planting a crop during the highest period of the weed flush and to time tillage tasks so that the biggest flush of weeds can be eliminated. Furthermore, as annual weeds show dramatic differences between species in both weed seed production and dormancy, this information can be used by growers to prioritize their weeding efforts, based on the problem potential of an individual species (Van Acker 2009, Table 1). For growers in the Mid-Atlantic, 'Weeds of the Northeast' by Richard H. Uva is an excellent printed resource, as are several online Cooperative Extension-sponsored sites (see: **Additional Resources** at the end of this chapter for links).

Table 1. Ranking, on a scale of 1-7, of several common annual weed species based on a combination of fecundity and persistence. After van Acker 2009.

Species	Family	Seed Longevity	Seed production	Problem Potential
Wild mustard	Brassicaceae	Medium	Low	2
Dandelion	Asteraceae	Low	High	3
Common chickweed	Caryolphyllaceae	High	Medium	4
Barnyard grass	Poaceae	High	High	5
Common lambsquarters	Chenopodiaceae	High	Very high	6
Redroot pigweed	Amaranthaceae	Very high	Very high	7

Crop Management Tactics for Controlling Weeds

Crop rotation is considered the foundation of weed management in organic vegetable production (Macrae *et al.*, 1993; Liebman and Davis, 2000; Watson *et al.*, 2002; Anderson, 2010). Crop rotation schemes consisting of different cash crops with similar management practices and timing of operations, does little to discourage the establishment and proliferation of annual weeds in vegetables. However, this production scheme is generally practiced on diversified vegetable farms. If executed properly, crop rotations can alleviate many of the insect, weed, and disease problems that organic growers face by providing greater diversity in crop type, planting date, resource competition, timing of tillage, and harvest date. Rotations can also add necessary slow-release nutrients back to the soil when leguminous plants are included in the rotation.

To be successful, crop rotation schemes should include a rest or “ley” period, where annual or perennial cover crops are grown instead of annual cash crops. The time of planting, choice of cover crop, and time of cover crop incorporation can all be manipulated to pre-empt establishment, growth, and seed rain of the most problematic weed species (Sarrantonio and Gallandt, 2003; Teasdale *et al.*, 2007). The duration and the proportion of land taken out of annual cash crop production may vary from farm to farm, depending on many factors, including cost of land, market availability, and the ability to integrate livestock. Some growers remove half of their land from production (Nordell and Nordell, 2009), while other growers, citing economic pressures, continuously crop their land (Hartz, 2002), which can be detrimental to soil quality

(Haynes and Tregurtha, 1999) and increase pest loads (Hummel *et al.*, 2002). Vern Grubinger, an Extension specialist in Vermont, recommends that a minimum of ¼ of arable land should be resting from cash crop production every year (Grubinger, 2001). For organic growers that are market-limited, continuous cropping is particularly counterproductive. Placing emphasis on exploiting the rotation effect to reduce yield and quality losses due to weeds, insects, and diseases, and also lower input costs from labor (hand weeding); OMRI-approved pesticides and imported fertilizers will result in getting the best product to market at the lowest cost and greater return.

Developing a successful crop rotation scheme takes both planning and trial and error. Rotations are unique to each farm, and must take into account biotic, abiotic, and economic considerations, including climate, soil type and fertility, precipitation, duration of the growing season, access to necessary equipment and labor, weed community present in the fields, and the farm's market. Cropping sequences will naturally evolve over time to incorporate these considerations, but the basic rotation should remain at the core.

It is important to consider the order of the crops being grown, with respect to probable seed rain, when developing rotations. For instance, potatoes and corn are known as "clean up" crops, because these crops are competitive and offer multiple opportunities for mechanized weed control with sweeps or shovels. These crops should precede crops that are more sensitive to competition from weeds or require a lot of hand weeding, like carrots and onions. Longer-season crops that do not offer a lot of opportunity for hand weeding or mechanical control, like vining melons and pumpkins, should not precede weed-sensitive crops, as the seed rain from the weeds in the melon year will result in an abundance of weeds the next season.

Beech Grove Farm's four year rotation provides an excellent example of a systematic rotation that also allows flexibility in terms of which cash and cover crops are planted every year (Fig. 3). In the four-year rotation, which includes alternate-year cover cropping, early vegetables are rotated with late vegetables, providing much needed diversity in timing of operations to manage weed populations. Winter-killed cover crops are planted the fall preceding early vegetables, to reduce the amount of field preparation and tillage required in the spring, when multiple days of cooperative weather is necessary to prepare and plant vegetables. Vigorous overwintering cover crops are planted before a late summer vegetable crop, to not only smother established weeds, but also provide significant biomass before natural senescence, flail mowing, or undercutting (Nordell and Nordell, 2009).

In addition to crop rotations, further efforts are often necessary to both decrease weed emergence and weeds surviving to reproduction. This means addressing the most long-lived part of the annual weed life cycle: the weed seedbank. It is from the weed seedbank that new weeds are recruited every year and to where weeds that have evaded control return their seeds. As weed emergence is typically a small percentage (2-10%) of the total amount of weed seeds in the soil, the weed seedbank is a type of “memory” of lapses in past weed management efforts. Due to innate and induced dormancy of weed seeds in the seedbank and the size of the weed seedbank on some farms, it will take multiple years of good control to reduce the weed seedbank.

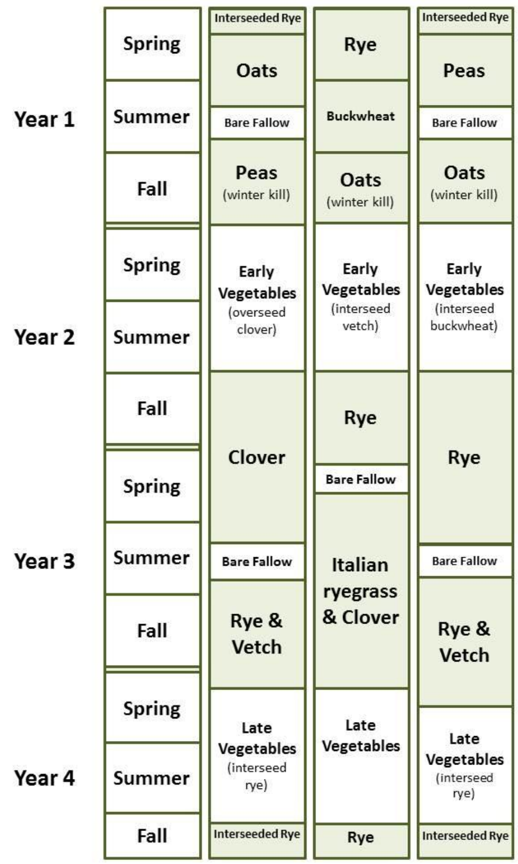


Figure 3. Variations on the four year crop rotation from Beech Grove Farm in Trout Run, Pennsylvania. Fields are only cropped to vegetables every other year, to allow for weed control and soil building. Early vegetables are rotated with late vegetables to increase the amount of crop diversity. After Nordell and Nordell (1999).

Methods for decreasing the weed seedbank center on two tactics: reducing the amount of weed seeds currently in the seedbank and preventing new seeds from entering the seedbank. The rest of this chapter will focus broadly on these two tactics.

Reducing the number of weeds in the weed seedbank

Without new input to the weed seedbank, it will decrease over time, due to losses from germination, predation, microbial decay, and age-related embryo degeneration (Gallandt, 2006). The rate of seedbank decline will vary with weed species and location, but to increase seedbank losses to germination, timed soil disturbances are necessary.

Summer Fallow

By purposely keeping cropland out of production during the growing season, growers can repeatedly cultivate land at two to three week intervals to deplete weed seedbanks and carbohydrate stored in perennial weed rhizomes. Repeated cultivations not only kill weeds, but also encourage a new flush by moving new weed seeds to an area of the soil layer that will allow them to germinate. When these fallow periods are timed to coincide with peak emergence of the most dominant species in a particular field, dramatic declines in weed seedbank can occur. For growers with exceedingly large weed seedbanks, this technique may be essential to getting weed problems under control in fields before attempting or resuming organic vegetable cultivation. Using bare summer fallow decreases soil organic carbon and increases erosion (Voroney *et al.*, 1981). Thus, the inclusion of this management practice should not comprise a significant proportion of crop rotations or be the principal method of weed control on a farm. Deleterious effects of a bare summer fallow on soil quality can be mediated by using shorter fallow periods or planting cover crops before and after the fallow period.

Stale Seedbed

The false or stale seedbed technique can be used to reduce competition from weeds in early- and mid-season direct-seeded vegetables. For this technique, fields are prepared two to four weeks ahead of planting date. Weeds are allowed to germinate and establish and then killed with either flaming or a light, shallow tillage once or twice prior to planting (Fig. 4). Timing is very important to the success of this method; if it is performed too early in the season, it may be too cold for warm season weed seeds to germinate in appreciable numbers. In dry years, the magnitude of the effect of the stale seedbed technique may be lessened, as inadequate soil moisture will enforce secondary seed dormancy and prevent weed seeds from germinating. In this instance, irrigation can be used to coax as many of the weed seeds to germinate as possible. It should be noted that each soil disturbance will encourage a new flush of weed seedlings, so vegetables should be planted soon after the last tillage event, within hours, to provide vegetables as much of a head start as possible.

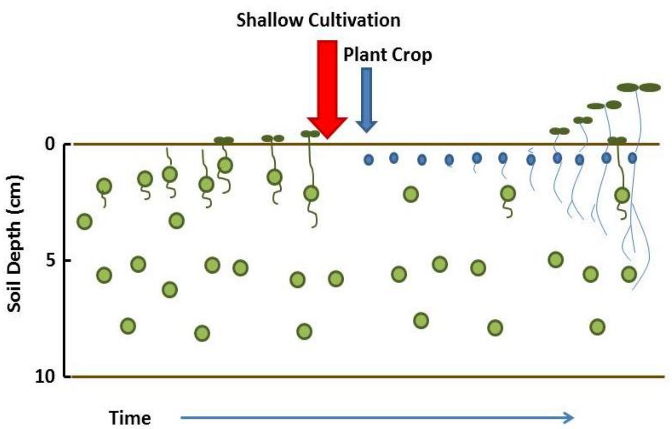


Figure 4. Illustration of the false seedbed technique. Weeds in the top few centimeters are allowed to germinate and killed with a shallow cultivation when they reach the “white thread” stage. The crop is planted immediately afterwards, to give it a head start. Seeds in the lower soil levels remain dormant.

This technique works well with transplanted vegetables. Because the slow, early growth period is partially completed in the greenhouse, once planted in the field, transplants are more competitive with newly emerged weed seedlings. Using transplants also gives growers a longer window of opportunity to use the stale seedbed technique without compromising harvest date. Though costs for seedlings and planting will be higher with transplants versus direct seeding, this may be outweighed by lowering the amount of manual weeding and increased yields.

Preventing New Seeds from Entering the Seedbank

The most important part of reducing seed inputs to weed seedbanks is reducing weed density. For many growers, this is accomplished by repeated cultivations. However, this is not possible in all annual vegetable crops, nor does it address the fundamental problem, which is that these weeds are filling an unused niche in crop fields. Preventing new weed seed production also includes growing more competitive vegetable cultivar such as those more adaptable to the growing environment of the farm, reducing the competitive ability of weeds, through mulches, cover crops, and resource management.

Manual and Mechanical Weed Control

Hand weeding constitutes an appreciable, but necessary, production cost for organic vegetable growers. Time spent hand weeding varies with the crop and its sensitivity to yield and quality losses due to weeds. However, efforts to reduce or eliminate seed rain in one crop will pay dividends in subsequent years with reduced weed populations.

To minimize labor costs for hand weeding, growers should consider investing in tools that can eliminate a large proportion of weeds in less time, either hand tools, wheel-mounted tools, or tractor-mounted tools. The most important consideration for any cultivation tool is that timing is everything: small weeds are the easiest to uproot or undercut and kill. As weeding is delayed, due to rain or other on-farm responsibilities, weeds grow bigger and become less susceptible to cultivation. Cultivation tools should not be the sole method of weed control, as rates of weeding efficacy can vary with weed size, soil moisture, and operators' experience. After initially weeding with tools, "weeders" should return to the field and remove the remaining weeds by hand. This reduces the overall time spent hand weeding and results in a high level of weed control.

There are a variety of tools available to manage weeds on farm, ranging in price, efficacy, and sophistication. On the inexpensive, simple side of the spectrum are hand tools, which encompass the perennially popular long-handled collinear and stirrup hoes, as wells as a variety of other specialty blade designs. These tools allow workers to weed while standing upright, have good precision, and cost less than $60 per tool.

Wheel hoes are the next level of weeding tool sophistication. These wheeled tools, which can have stirrup hoes, sweeps, or hillers attached, allow a faster working rate, but do not have the same precision or efficacy of either hand tools or hand weeding, because they cannot be worked as close to the crop row. They can also be a bit awkward and tiring to operate, as it requires a push-pull movement to undercut weeds below the soil surface. However, these tools are likeable because of their efficiency.

They increase the amount of ground that is weeded in a given time period and are well-suited to small-scale operations.

The next step up is the use of tractor-mounted tools. Factors including the size of the operation, the level of weed pressure, and available capital will all influence the decision to pursue increased mechanization of weed control. The most difficult weeds to control mechanically are those located between plants and close to the crop row. Controlling these weeds with tractor-mounted instruments will require expensive, special equipment, well beyond the capability of many small-scale growers. Furthermore, many of the popular tools for control of intra-row weeds (rolling baskets, finger weeders, and spyder weeders) are not designed to handle heavy organic residues, so may not be appropriate for every farm or farm plan. *e*Organic has an excellent set of videos of organic vegetable growers and their custom and purchased tools for weed management which can be viewed at http://www.extension.org/pages/18436/video:-vegetable-farmers-and-their-weed-control-machines.

Late-Season Weed Control

Short season crops like leaf lettuce provide an excellent opportunity to both harvest a crop and pre-empt seed rain of weeds that have a longer life cycle than the crop. For longer-season crops, manual removal, or rogueing, of large weeds that have escaped previous control efforts is a good way to reduce seed rain, even if these weeds do not have a direct impact on yield the current cropping season. After the crop has been harvested, fields should be mowed or disked to keep mature weeds from setting seed. If weeds have already set seed, it may be a good idea to just mow the fields, in order to keep as many seeds on the soil surface as possible, where they are subjected to greater levels of predation and extreme temperature fluctuations that can reduce their viability.

Fertility Management

Organic growers should strive to build up soil fertility by adding organic residues (compost, animal manure, cover crop, green manure, off-farm residue) which slowly releases plant available nutrients as they decompose. This has several potential benefits: first, healthy soils full of organic matter host a greater diversity of soil microorganisms and invertebrates, which can enhance both weed seed decay and predation (Gallandt *et al.*, 1998; Fennimore and Jackson, 2003). Second, by providing a majority of the crop's nutrient needs through soil amendments, this method reduces the amount of purchased fertilizers and concurrently lowers production cost. Lastly, broadcast application of readily-available nutrients can stimulate weed seed germination (Kirkland and Beckie, 1998), and although N fertilizers improve crop yields, weeds are often more competitive with crops in fields with higher soil nutrient levels (Di Tomaso, 1995). Thus, crop managers who apply fertilizer should consider banding or side dressing the fertilizer in the crop row as opposed to broadcasting. This method has been shown to reduce weed competitiveness while increasing crop competitiveness and overall yield (Rasmussen *et al.*, 1996; Melander *et al.*, 2003; Blackshaw *et al.*, 2004).

Cover Crops

Cover crops perform many vital functions in agroecosystems. Used in place of a bare fallow, cover crops add organic matter to the soil, prevent erosion and nutrient leaching, provide a habitat for beneficial insects, and in the case of legumes, fix atmospheric nitrogen (Kuo *et al.*, 1997; Dabney *et al.*, 2001; Snapp *et al.*, 2005). Cover crops compete directly with weeds for resources as they develop their extensive canopies and deep root systems. The cover crop canopy extinguishes light cues needed for weed seed germination and some cover crops exhibit allelopathic tendencies, meaning they exude chemicals which can inhibit the germination and growth of weeds (Creamer *et al.*, 1996). Further, properly timed mowing or incorporation of cover crops can disrupt weed growth and weed seed production, reducing weed populations in subsequent crops.

To ensure that a cover crop suppresses weeds and reduces weed seed production requires more than merely planting cover crop seeds into a field. Farm managers should choose species and varieties that have rapid growth to get the most weed suppressive effect out of their cover crop. Selection of cover crop species should also be compatible with other pest management goals. For instance, forage radish, a winter-kill cover crop that is touted for its N scavenging and ability to break up plow pan, shares the same insect pests and diseases with *Brassica* vegetables, so it may be problematic to plant it before a *Brassica* crop. Growers who plant winter cover crops should make sure that they are planted on time, as planting them too early or late in the fall may impact their overwinter survival. Adequate fertility and appropriate seeding rates are also necessary to ensure a healthy, thick, and competitive stand. These stands should be monitored for weed growth and proliferation, so if a cover crop is not performing as expected, the crop can be terminated before the weeds set seed.

After cover crops growth is terminated, through natural senescence, mowing, or other cultural tactic, these residues can continue to suppress weeds, conserve moisture, and reduce erosion if they are left on the soil surface, as in low-till or no-till production. As cover crop residues break down, their ability to physically limit weed seed emergence declines, so these residues will not provide season-long control. Additional mulching, cultivation, or a combination or living mulches and mowing will be necessary to restrict weed growth and proliferation. For more information regarding different types of cover crops, see the **Additional Resources** section at the end of the chapter.

Suppressing weeds with mulches

Living Mulches

Living mulches, or smother crops, differ from cover crops in that they are grown at the same time as the cash crop, usually between cash crop rows, and maintained throughout the cash crop growth cycle. Like cover crops, living mulches reduce erosion, increase soil organic matter, provide habitat for beneficial insects, and compete with weeds for sunlight and nutrients (Altieri *et al.*, 1985). The difficulty with living mulches is balancing how these crops suppress weed recruitment and growth without competing with the cash crop. Living mulches can be mowed to manage their growth, and therefore, reducing their competitiveness with cash crops, but this management practice will not be compatible with all annual cropping practices, especially vining crops. Other options include planting low growing living mulches that cover the soil surface but are less likely to shade out the cash crop, using drought tolerant living mulches that may not compete with the cash crop for soil moisture, and using “dying mulches”. Dying mulches are living mulches that start to senesce prior to completion of the cash crop life cycle. Dying mulches can compete with and provide weed control during the critical stage of crop growth without competing with crops. Given the multiple benefits of living mulches in terms of sponsoring biodiversity, suppressing insect and disease pests, and improving soil health (Hooks *et al.*, 1998; Manandhar and Hooks, 2011; Wang *et al.*, 2011), living mulches will continue to receive attention from researchers in order to make this system more suited to annual vegetable production systems.

Plastic Mulches

Plastic mulches are useful for suppressing many within-row and close to the row weeds, which are difficult to remove with tractor-mounted cultivation equipment and too labor intense to remove with hand tools. These synthetic mulches also warm the soil, resulting in increased yields for crops that favor warmer soils. The plastic film prevents light from reaching the soil surface, which hinders the growth of many, but not all weeds. Members of the nutsedge family, yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*), are not controlled with this method, as their sharp foliage enables these plants to pierce and emerge through the plastic barrier. Holes in the plastic for transplants and tears will allow other weed seeds to germinate and grow. Black plastic mulch is also expensive to buy, install, and remove, costing approximately $275-$350 an acre (McCraw and Motes, 2007).

Biodegradable Mulches

Biodegradable mulches perform similarly to black plastic mulches, but can be tilled into the soil at the end of the season. Though biodegradable mulches are anywhere from two to three times the cost of standard black plastic at the outset, these mulches eliminate the labor and landfill fees associated with black plastic disposal at the end of the season, reducing overall costs (DuPont, 2010). Biodegradable mulches are generally made from proprietary materials derived from corn or potato starch and not all are currently OMRI approved. Trials conducted at Cornell University have shown no difference in early or total yields between biodegradable and black plastic mulches (Rangarajan and Ingall, 2006), while trials from Penn State reported mixed results, depending on the crop (DuPont, 2010). Durability through the season also varies with the product and manufacturer.

Organic mulches

Thick mulches of organic material, such as straw, compost, wood chips, shredded leaves, and sawdust, can also be used to suppress weeds between and within the rows of cash crops. Organic mulches improve soil health by increasing soil organic matter, thus providing food for many soil organisms while conserving soil moisture. However, several of these organic mulches are high in cellulose (high C:N ratio). Thus, when turned under, the soil organisms that break down these mulches tie up much of the free nitrogen in the soil making it unavailable for plant uptake and contributing to N deficiencies in subsequent crops. It is better to use high-carbon mulches, e.g. sawdust and wood chips, in perennial beds or alleyways, so that they will slowly decompose over time instead of being incorporated into the soil during one time period. Expense and availability are other factors to consider, especially as farm size increases. But local sources of free bark mulch from tree trimming companies or leaves from nearby municipalities are good mulch sources. For warm season crops, it is best to wait until the ground has warmed to apply mulches, so as to avoid insulating the cool air in the soil.

Sanitation

Harvest and tillage equipment can help spread weed propagules. Farm equipment or supplies should be cleaned thoroughly to remove weed seeds, especially if travelling between different farms or fields with dissimilar weed communities. Remember, prevention is easier than dealing with the control of a new-to-you invasive weed. Off-farm transplants should be inspected for the presence for weed propagules before planting, as should hay and straw mulches. Any compost used on a farm should be aged appropriately to kill any viable weed seeds that may be within the compost (inner temperatures 180 degrees sustained for 72 hours) and compost piles maintained to prevent the establishment and growth of weeds on the piles. Hedgerows, alleyways, and headlands should be mowed to limit immigration of weeds from the field edges. For perennial weed management, consider leaving a vegetative strip along the field border to prevent creeping perennials from establishing in the field and provide other ecosystem services (e.g., increasing biodiversity, providing food for foraging bees, butterflies, and etc.). The vegetative buffer can be mowed occasionally as needed to suppress weeds.

Conclusions

Organic producers face many obstacles in trying to get their products to the market and it can be difficult to balance competing concerns regarding farm profitability, soil health, weather, insect and disease management, and quality of life. All these factors affect the ability of farm managers to implement timely non-chemical weed management tactics. At times, efforts to control one pest can be at odds with other farm goals. For example, the extensive use of cultivation to control weeds may have a negative effect on soil health by reducing population of beneficial soil organisms involved in nutrient cycling. Tackling weeds in organic vegetables requires addressing the weed seedbank. This is a long-term process and it is important to note that the tactics discussed earlier will not work independently to solve weed problems, nor will they eliminate the need for hand weeding. Organic cropping systems that better mimic natural ecosystems will be far more sustainable both ecologically and economically in the long-term than farms that have a greater propensity to mirror conventional production systems by relying on OMRI-approved substitutes for weed, disease, and insect management (Macrae *et al.*, 1993; Altieri, 1999). This will require growers to experiment with several management tactics concomitantly to determine what combination works best for the unique requirements of their farm.

Additional Resources

Weed Identification

Virginia Tech Weed Identification Guide (including grass key):
http://www.ppws.vt.edu/weedindex.htm

University of California web-based weed identification guide:
http://www.ipm.ucdavis.edu/PMG/weeds_intro.html

University of Illinois Weed Identification Guide:
http://weeds.cropsci.illinois.edu/weedid.htm

Cover Crops

University of California Davis cover Crop Database:
http://www.sarep.ucdavis.edu/ccrop/

Sustainable Agriculture Network's Managing Cover Crops Handbook:
http://www.advancedagsolutions.com/resources/covercropsprofit2.pdf

Weed Control Tools

Vegetable Farmers and their Weed-Control Machines:

http://www.extension.org/pages/18436/video:-vegetable-farmers-and-their-weed-control-machines

Acknowledgements

The writing of this article was supported in part by the U.S. Department of Agriculture National Institute of Food and Agriculture Organic Research and Extension Initiative Award no. 2010-51300-21412 "Using Winter Cover Crops to enhance the Organic Vegetable Industry in the Mid-Atlantic Region".

Literature cited

Aldrich, R., 1984. Weed-crop ecology: principles in weed management. Breton, North Scituate, MA, USA.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agriculture Ecosystems & Environment 74, 19-31.

Altieri, M.A., Wilson, R.C., Schmidt, L.L., 1985. The effects of living mulches and weed cover on the dynamics of foliage- and soil-arthropod communities in three crop systems. Crop Protection 4, 201-213.

Anderson, R.L., 2010. A rotation design to reduce weed density in organic farming. Renewable Agriculture and Food Systems 25, 189-195.

Baker, H.G., 1974. The Evolution of Weeds. Annual Review of Ecology and Systematics 5, 1-24.

Blackshaw, R.E., Molnar, L.J., Janzen, H.H., 2004. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Science 52, 614-622.

Bylterud, A., 1965. Mechanical and chemical control of *Agropyron repens* in Norway Weed Research 5, 169-180.

Creamer, N., Bennett, M.A., Stinner, B.R., Cardina, J., Regnier, E.E., 1996. Mechanisms of weed suppression in cover crop-based production systems. American Society for Horticultural Science, Alexandria, VA, USA.

Dabney, S., Delgado, J., Reeves, D., 2001. Using winter cover crops to improve soil and water quality. Communications in Soil Science & Plant Analysis 32, 1221.

Di Tomaso, J.M., 1995. Approaches for Improving Crop Competitiveness through the Manipulation of Fertilization Strategies. Weed Science 43, 491-497.

DuPont, T., 2010. Biodegradable mulches. Pennsylvania State University Cooperative Extension, State College, PA.

Fennimore, S.A., Jackson, L.E., 2003. Organic Amendment and Tillage Effects on Vegetable Field Weed Emergence and Seedbanks. Weed Technology 17, 42-50.

Gallandt, E.R., 2006. How can we target the weed seedbank? Weed Science 54, 588-596.

Gallandt, E.R., Liebman, M., Corson, S., Porter, G.A., Ullrich, S.D., 1998. Effects of Pest and Soil Management Systems on Weed Dynamics in Potato. Weed Science 46, 238-248.

Graglia, E., Melander, B., Jensen, R.K., 2006. Mechanical and cultural strategies to control *Cirsium arvense* in organic arable cropping systems. Weed Research 46, 304-312.

Groves, R.L., Walgenbach, J.F., Moyer, J.W., Kennedy, G.G., 2001. Overwintering of Frankliniella fusca (Thysanoptera: Thripidae) on Winter Annual Weeds Infected with

Tomato spotted wilt virus and Patterns of Virus Movement Between Susceptible Weed Hosts. Phytopathology 91, 891-899.

Grubinger, V., 2001. Organic vegetable production: Managing nutrients and pests.

Håkansson, S., 1983. Seasonal variation in the emergence of annual weeds — an introductory investigation in Sweden. Weed Research 23, 313-324.

Hartz, T.K., 2002. Sustainable vegetable production in California: Current status, future prospects. Hortscience 37, 1015-1022.

Haynes, R.J., Tregurtha, R., 1999. Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. Biology and Fertility of Soils 28, 259-266.

Hooks, C.R.R., Valenzuela, H.R., Defrank, J., 1998. Incidence of pests and arthropod natural enemies in zucchini grown with living mulches. Agriculture, Ecosystems & Environment 69, 217-231.

Hummel, R.L., Walgenbach, J.F., Hoyt, G.D., Kennedy, G.G., 2002. Effects of production system on vegetable arthropods and their natural enemies. Agriculture, Ecosystems & Environment 93, 165-176.

Ivany, J.A., Sweet, R.D., 1973. Germination, Growth, Development, and Control of Galinsoga. Weed Science 21, 41-45.

Kirkland, K.J., Beckie, H.J., 1998. Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum*). Weed Technology 12, 507-514.

Kuo, S., Sainju, U.M., Jellum, E.J., 1997. Winter Cover Crop Effects on Soil Organic Carbon and Carbohydrate in Soil. Soil Sci. Soc. Am. J. 61, 145-152.

Liebman, Davis, 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Research 40, 27-47.

Macrae, R.J., Henning, J., Hill, S.B., 1993. Strategies to overcome barriers to the development of sustainable agriculture In Canada - The role of agribusiness. Journal of Agricultural & Environmental Ethics 6, 21-51.

Manandhar, R., Hooks, C.R.R., 2011. Using Protector Plants to Reduce the Incidence of Papaya Ringspot Virus-Watermelon Strain in Zucchini. Environmental Entomology 40, 391-398.

McCraw, D., Motes, J.E., 2007. Use of plastic mulch and row covers in vegetable production Oklahoma State University Fact Sheets. Oklahoma Cooperative Extension Service, Stillwater, OK.

Melander, B., Cirujeda, A., Jørgensen, M.H., 2003. Effects of inter-row hoeing and fertilizer placement on weed growth and yield of winter wheat. Weed Research 43, 428-438.

Nordell, A., Nordell, E., 2009. Weed the soil, not the crop. Acres USA, Austin, TX.

Norris, R.F., Kogan, M., 2005. Ecology of interactions between weeds and arthropods Annual Review of Entomology 50, 479-503.

Rangarajan, A., Ingall, B., 2006. Biodegradeable Mulch Product Testing. Ithaca, NY.

Rasmussen, K., Rasmussen, J., Petersen, J., 1996. Effects of fertilizer placement on weeds in weed harrowed spring barley. Acta Agriculturae Scandinavica Section B-Soil and Plant Science 46, 192-196.

Sarrantonio, M., Gallandt, E.R., 2003. The role of cover crops in North American cropping systems. Journal of Crop Production 8, 53-73.

Snapp, S.S., Swinton, S.M., Labarta, R., Mutch, D., Black, J.R., Leep, R., Nyiraneza, J., O'Neil, K., 2005. Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches. Agron. J. 97, 322-332.

Teasdale, J.R., Brandsæter, L.O., Calegari, A., Skora Neto, F., 2007. Cover crops and weed management. In: K., U.M., E., B.R. (Eds.), Non-chemical weed management: principles, concepts and technology CAB International, Wallingford, UK, pp. 49-64.

Timmons, F.L., Bruns, V.F., 1951. Frequency and depth of shoot-cutting in eradication of certain creeping perennial weeds Agron. J. 43, 371-375.

Van Acker, R.C., 2009. Weed biology serves practical weed management. Weed Research 49, 1-5.

van Heemst, H.D.J., 1985. The influence of weed competition on crop yield. Agricultural Systems 18, 81-93.

Vengris, J., 1953. Weed Populations as Related to Certain Cultivated Crops in the Connecticut River Valley, Mass. Weeds 2, 125-134.

Voroney, R.P., Vanveen, J.A., Paul, E.A., 1981. Organic-C dynamics in grassland soils. 2. Model validation and simulation of the long term effects of cultivation and rainfall erosion Canadian Journal of Soil Science 61, 211-224.

Wang, K.H., Hooks, C.R.R., Marahatta, S.P., 2011. Can using a strip-tilled cover cropping system followed by surface mulch practice enhance organisms higher up in the soil food web hierarchy? Applied Soil Ecology 49, 107-117.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R., Rayns, F.W., 2002. Managing soil fertility in organic farming systems. Soil Use and Management 18, 239-247.