Managing weeds in vegetables organically

Cerruti R2 Hooks1, Alan W. Leslie2 & Guihua Chen2

1Associate Professor and Extension Specialist and 2Postdoctoral Research Associate
UMD Department of Entomology

Introduction
Weed management is more challenging in organic crops and accounts for a large portion of production costs. As such, managing weeds is a major economic constraint to the organic vegetable industry, and comparisons of weed communities between conventional and organic farming systems consistently demonstrate higher weed levels in organic systems. For years, organic growers have identified weed management as a top production constraint and research priority with some specifying that they have “serious difficulty” managing weeds. Hand-weeding is impractical if significant human labor hours are needed and the cost of organic herbicides makes their use impractical when used over the entire field at rates necessary for adequate weed suppression. Clove oil, for example, can control broadleaf weeds at high concentrations. However, its cost makes broadcast applications impractical, even in high-value vegetable production systems. Further, organic herbicides when used after crop emergence may result in crop injury, and many organic acceptable herbicides are only moderately effective.

Currently, most strategies utilized for managing agricultural weeds in many organic cropping systems rely heavily on tillage, but repeated soil disturbances have a detrimental impact on soil structure and overall health. These aforementioned hindrances are coercing organic producers to seek other weed management solutions; and overcoming these issues requires organic farmers to adopt an integrated approach to managing weeds. Integrated weed management (IWM) combines the use of chemical, cultural, genetic, biological and mechanical practices, so as to reduce reliance on a single weed management tactic. None of these tools if used individually are expected to provide acceptable levels of weed suppression for an extended time period. Thus, multiple tactics that enhance weed control by preventing weed seed germination and reducing the weed seedbank must be combined for best results. If various IWM tools are employed in a methodical manner, over time, acceptable and sustainable weed management levels can be achieved.

Plant diversity & cover crops. Increasing cropping system diversity has been advocated as a means of reducing chemical inputs for weed control. Many studies have compared weed populations in simple and diverse crop plantings including organic systems. Growing two or more crops within the same field can result in fewer weed problems because the soil is more covered. Generally speaking, intercrops that include species with rapid, early growth and dense, vigorous canopy formation over the soil surface will be most weed suppressive. A leek-celery intercrop decreased relative soil cover of weeds by 41% and reduced the density of common groundsel (Senecio vulgaris) by 58% compared to sole cropping. However, some difficulties of mixed cropping are intercrop competition and added intricacies associated with managing two
crops within the same field. Thus, from a weed management perspective, inter-planted “smother crops” may be viewed as a valuable tool for suppressing weeds or a hindrance to efficiently managing weeds using conventional methods. In principle, companion crops can be chosen to complement the main crop in resource use while directly or indirectly interfering with weeds, thereby suppressing weed but not crop growth.

Cover crops can be used also to increase within crop diversity. Research has shown that cover crops can be used to help manage weeds and that they can play an important role in an IWM vegetable system. Cover crops can generate a competitive crop environment for water, light and nutrients within 4 to 8 weeks after sowing. Weed suppressive ability of cover crops can be attributed to their fast emergence, rapid canopy development and root growth. Thus, highly competitive cover crops that grow rapidly and develop a dense canopy are more likely to prevent weeds from establishing. Cover crops prevent weed germination and seedling establishment via allelopathy, altered environmental conditions and/or formation of physical barriers. Cover crop species sown in late summer can reduce growth of winter annual and perennial weeds such as quackgrass (*Elymus repens*) during fall and winter. Annual or short-term perennial cover crops can be used on otherwise fallow fields to compete with weeds for resources needed to proliferate in a field.

After cash crops are planted, cover crops may still be used as residue or living mulch to continuously suppress weed populations during the cropping cycle. One of the most effective methods is using cereal or legume cover crops with physical and allelopathic weed-suppressing properties. Residues of some mulched and undersown cover crops can prevent weed seed germination and growth, especially in spring when these residues decompose into chemical constituents. If inter-planted with a vegetable crop as a living mulch, the cover crop chosen should complement the main crop in resource use while directly or indirectly suppressing weed growth, thereby inhibiting weeds without negatively impacting the crop. For more information on cover crops and weed suppression refer to: ([https://extension.umd.edu/learn/offing-cover-crops-weed-suppression-featuring-roller-crimper-and-other-mechanical-contraptions](https://extension.umd.edu/learn/offing-cover-crops-weed-suppression-featuring-roller-crimper-and-other-mechanical-contraptions)).

*Tillage/cultivation.* Organic farmers have several options for suppressing weeds after they have emerged including hand removal (pulling, hoeing, digging, or cutting), herbicides, mowing, and cultivation. There are a variety of cultivation tools that can be used to control emerged weeds and disrupt their lifecycle including mechanical and flame cultivation. Mechanical cultivation is a mainstay of many organic weed management programs. The effectiveness of inter-row cultivation in suppressing weeds in organic production systems is well known. Cultivation is influenced by weather, soil type and crop canopy features. The timing of cultivation will vary according to weed species present in the field but should be based on the critical weed-free period of the cash crop. Cultivation suppresses weeds by burial, uprooting, root desiccation, and/or a physical separation or crushing of plant parts.

When perennial weeds are present, tillage may be the most viable option. For example, in a field where multiple perennial weed species are uncontrollable by other means, intensive post-harvest cultivation followed by deep inverting tillage can diminish the weed problem. This
extreme approach should be limited to the smallest area possible to quell the problem. The type of tillage equipment used will be mostly dependent on the targeted weed rooting system. For example, if the weed requires the root be broken up into fragments, a rotovator or cultivator can be used. Some rhizomes require that they be dragged and exposed to the soil surface or removed. A cultivator or harrow may be used to accomplish these tasks. Tubers or bulbs need to be cut when the rhizomes are present and dug up for exposure to adverse conditions (frost or drought), which can be done with moldboard or disk plowing. There are a number of new tillage and cultivation instruments on the market that may be used on annual and perennial weeds. The success of many mechanical operations targeting perennial weeds depends on timing of their execution. However, it is critical to have reliable information on the weed’s biology so that the best equipment and timing of operation for exploiting the targeted weed’s weak link are used.

Though tillage/cultivation has been a keystone in weed management, limitations with current cultivation tools include: high purchase and maintenance costs, marginal efficacy, excessive soil disturbance, stimulation of latent weed seed germination, and narrow applicability across a range of soil types, soil moisture conditions, and weed growth stages. Some fear that soil quality and health may decrease under continuous cultivation. Frequent inter-row cultivation is associated with enhanced soil erosion and new weed flushes. Further, tillage uses large amounts of fossil fuel and is the most energy-consuming task among all field operations, subsequently representing an additional cost to farmers. The distribution of weed seeds through the soil profile can be associated with the amount of soil disturbances, and changes in tillage practices can influence weed seed viability, weed size, and weed community composition and diversity.

High fuel costs and the need for soil conservation have prompted the adoption of conservation tillage practices for vegetables. Reduced or conservation tillage is any method of soil cultivation that leaves plant residue on fields before and after planting the next crop. There are several different conservation tillage practices. No-till and strip-till involve planting crops directly into residue that either hasn't been tilled (no-till) or has been tilled only in narrow strips while the rest of the field remains untilled (strip-till). Ridge-till involves planting row crops on permanent ridges about 4-6 inches high. The previous crop's residue is cleared off ridge-tops into adjacent furrows to make way for the new crop being planted on ridges. Mulch-till is any other reduced tillage system that leaves at least one third of the soil surface covered with plant residue. In conservation tillage systems, cover crop residue that remains on the soil surface may prevent weed establishment. In addition to residue, cover crops can be used as living mulch (living ground cover) to help prevent weed establishment. In reduced-tillage systems, most weed seeds remain at or near the soil surface, where they are exposed to greater mortality from predation and decay and are more susceptible to sterile seedbed tactics. In combination with proper weed suppression, weed seedbanks can diminish over time in reduced-tillage systems. Benefits of reduced tillage include less fuel use, reduced soil erosion, and water conservation. Growers can save from 30 to 40% in time, labor, machinery investment, and fossil fuels in conservation compared with conventional tillage.
Although reduced-tillage offers many ecofriendly and monetary benefits, a major compromise to operating under less tillage is the loss of a weed control tool. Hand-weeding is labor intensive and time-consuming, so it is not a practical alternative in large-scale production. Moreover, yields under reduced-tillage may not be comparable with conventional tillage if weeds are not managed, and may increase the chance for the occurrence of perennial weed problems.

Flaming. Flaming has been historically used primarily as a preemergence treatment, either prior to planting or before crop emergence. Alternatively, flaming can be used after crop emergence or planting in tolerant crop species, a process referred to as selective flaming. Flamed weeds either die or their competitive ability with cash crops can be severely reduced. Flaming may be used for instances in which cultivation or other weed management tactics are not practical. For example, controlling weeds in crops with shallow roots such as onion through cultivation can be challenging as cultivating too close to the crop can easily damage the root system. Therefore hand-weeding is often required but at considerable expense. Although interrow weeds can be effectively controlled through mechanical cultivation, weeds that grow within the row are more difficult to control as cultivation is either ineffective or causes unacceptable levels of crop damage. Flame weeding can be used to control weeds within the crop row where mechanical cultivation is difficult and help reduce or eliminate the amount of costly hand-weeding required. Some hand-weeding or mechanical measures may be required in addition to flaming in order to reduce weed populations sufficiently to maintain yields, and the susceptibility of weeds to flaming, largely depends on their heat avoidance, heat tolerance or both. Some studies have shown plants to be more sensitive when flamed in the afternoon than early in the morning. It is believed that this coincides with the time plants have the lowest relative leaf water content. As such, flaming in the afternoon might result in better weed control. Another potential pitfall of flaming is that studies have shown flaming to have a greater effect on broadleaf than grass weeds. Thus, if grass weeds are the dominant problem, flaming may not effectively suppress weed growth.

Land selection. A general rule is to avoid planting vegetables in fields with a history of heavy weed infestations, especially perennial weeds. Vegetables should be grown on land with at least a two-year history of effective weed control. If weed-infested fields can’t be avoided and planting vegetables is the only option, the most competitive crops should be planted in the most weed-infested fields and the least competitive in the cleanest fields. Examples of good vegetable competitors include cabbage and artichokes. Relative to many other vegetables grown in temperate latitudes such as onions, carrots, or peppers, these two crops quickly cover the soil making it more difficult for weeds to get established. Crops that grow slowly and cover the soil sparsely may suffer competition for water, nutrients, light, and space. When possible, heavily weed-infested fields should be set aside or planted as fields with non-row crops such as alfalfa or perennial cover crops. This long term coverage should help prevent further buildup of weeds.

Crop rotation. Crop rotation is probably the most important IWM tool and should be the cornerstone of any weed management plan. Crop rotation was considered an essential practice
for obtaining healthy crops and yields but as more agrochemicals and genetically modified crops came on the market, crop rotation became less utilized. Continuous planting of a single crop or crops having similar management practices allows certain weed species to become dominant in the system and, over time, these weed species become hard to manage. A good crop rotation scheme is not simply an avoidance of planting the same crop continuously in one area. To be most effective, crop rotation should involve a more elaborate system. Each crop within a rotation should differ drastically from its predecessor in one or several important characteristics such as planting or maturation dates, growth habit, competitive ability, associated cultural practices, and fertility requirements. The goal of crop rotation is to create an ever-changing environment within the field so as to prevent the dominance of particular weed species. Knowledge of potential weed problems in a field is critical as it allows farmers to implement a rotation strategy that is best suited for a particular field. For example, if late-germinating weeds are problematic, planting an early crop that gets established and covers the ground early may be a viable option.

For any rotation plan, related vegetables should not be grown in the same location in successive years as this produces predictable environmental conditions that weeds will exploit. In addition, alternate crops with different types of vegetation such as leaf, root, bulb, and fruit crops, rotate grass and dicots (e.g., field corn, vegetables), alternate different crops with different planting times as changing the seeding date from year to year means that specific weeds cannot become accustomed to environmental situations. Avoid planting crops of the same family back to back such as Solanaceae (e.g., tomato after eggplant), Cucurbitaceae (e.g., summer squash followed by cucumbers), Brassicaceae (e.g. broccoli after cauliflower), and alternate poor (e.g., onion) and high weed competitors (e.g., potato). Weeds tend to thrive in the presence of crops whose growth necessities and features are similar to their own. In such instances, production practices meant to benefit the cash crop may promote the growth and development of certain weed species. Thus, if there are problematic weeds in a field that are associated with a particular crop or that do well within a specific crop, avoid planting that crop in fields in which those weeds exist and instead plant crops which make conditions less conducive for those weeds to proliferate.

Another tactic is to rotate cool- with warm-season crops such as winter grains or sods with vegetables. Crops with different lifecycles provide more opportunities for growers to control weeds before seeds are produced. For example, most vegetables are summer annuals. As such, the inclusion of winter annual crops such as wheat into rotations may be an important tool for disrupting the lifecycle of problematic summer annual weeds in vegetable systems. Because winter wheat is well established in early spring, problematic summer annual weeds have little chance of establishing and producing seeds. Therefore, for weed species with low seed persistence, avoidance of seed production may result in rapid reductions in weed seedbank densities. For example, seed production of warm-season weeds can usually be eliminated during years in which early planted, cool-season crops are grown, with similar control of cool-season weeds occurring during years of warm-season crops. By preventing replenishment of the seed
bank, the natural decline of weed seed density in soil through time reduces the number of seedlings emerging in crops in later years.

Remember, a successful crop rotation plan changes conditions within the field habitat to the point that weeds’ lifecycles are disrupted. With that in mind, farmers should design a rotation so that weeds in their fields are constantly encountering varying or unpredictable environmental conditions from year to year. The greater the complexity and diversity of the rotation scheme the less likely a particular weed or additional crop pest will proliferate. A study was conducted in organic soil in Canada where there are severe infestations of nodding beggarticks (*Bidens cernua*), Canada fleabane (*Conyza canadensis*), and root-knot nematode (*Meloidogyne hapla*) due to continuous production of carrots in the same fields. A study was conducted to compare six 3-year crop rotation schemes with 3-years of carrot monoculture in a field in which carrot had been repeatedly grown for 10 years. Onion (*Allium cepa*), barley (*Hordeum vulgare*) or a weed fallow were included in the rotation. Each rotation ended with carrots being planted in year 3. Results showed that two consecutive years of row crops such a carrot-carrot or carrot-onion favored the maintenance of high weed pressure but weed populations decrease with barley in the rotation. When considering all aspects of the problems encountered in the field (weeds, root-knot nematodes, soil erosion and subsidence), the 3 year crop rotation sequence consisting of onion and barley performed the best, and was the wise alternative to carrot monoculture. Reviews of studies comparing simple with diverse crop rotations in the absence of herbicides suggest that more diverse rotations result in lower total weed density and greater weed diversity than simple rotations. Diverse crop rotations may reduce the dominance of a narrow range of weed species, since they confront weeds with more complex patterns of stress associated with different management practices. At the same time, diverse cropping sequences promote diversity by creating niches for a wider range of weeds than monocultures. Still, rotations should be evaluated regularly to make sure that no problems weeds are “beating” the crop rotation system and to make adjustments as needed.

Increasing crop rotation interval may not be viable economically for growers with limited good land and a high level of crop specialization. Improving the cropping system with use of cover crops between and within growing seasons might be more acceptable as it is less disruptive to the production system. In addition, the impact of a particular crop sequence may be less important than weed management practices used in that sequence, and in those instances that a “good” crop rotation scheme cannot be implemented, it is important that diverse management tactics are implemented. In high-value vegetable crops with few herbicide options, crop rotation can be an especially important component of an IWM program. Within these systems, rotation strategies to reduce weed density include (1) inserting highly competitive and easy to weed “cleaning” crops like potato (*Solanum tuberosum*), (2) rotating crops with different planting timings and durations, and (3) including cover crops during periods when soils might otherwise be bare. Rotations involving different planting dates and duration can be particularly beneficial for managing certain weeds.
Sanitation. Human activity can be the main culprit for introducing weeds onto a farm and into new areas within the farm. Appropriate sanitation can prevent weeds from spreading between fields and reduce the spread of weeds from neighboring landscape to crop fields. Farm equipment should be cleaned regularly. A study at Montana State University showed that a vehicle driven through a spotted knapweed infestation picked up about 2000 seeds of the weed, of which 90% dropped within 10 miles. Contaminated seed and uncleaned agricultural implements can be common sources of weed invasions. Using certified seed that is free of weed seeds and cleaning farm equipment after use in weed-infested fields are two simple practices that can be used to help prevent weeds from entering fields and spreading throughout the farm. Seeds should be purchased from reputable sources and inspected prior to and after planting. All soil should be cleaned from cultivation, tractor, mowing, and harvesting equipment, and other farm supplies such as pallets and bins. Power washes will do a better job removing soil than a garden hose. Animal manures and other material should be composted thoroughly to kill off weed seeds. Any mulch or compost that is applied should be free of weed seeds prior to use. Practices such as cleaning vehicles, equipment, animals, or maintaining livestock in weed-free areas before moving them can prevent dispersal, establishment, and persistence of weed seeds or rhizomes in previously weed-free areas.

Uncropped areas can be important sources of weeds and new weed invasions. Prevent weed influxes by scouting field edges and neighboring crop fields for weeds. Keep alleys and areas on the farm mowed or harrowed. Ditch banks can be major sources of problematic agricultural weed seeds that ingress into neighboring crop fields. Remove problem weeds in ditches and growing around buildings. Weeds outside of fields should not be taken lightly, if left unchecked, they will eventually make their way into nearby production fields. Paying close attention to sanitation and seed sources and managing weeds outside crop fields are all important in helping to prevent the introduction and movement of weeds into a farm and between areas within a farm.

Weed seed mortality. A primary aim of integrated weed management should be to prevent weeds from setting seeds, which will reduce weed pressures in future growing seasons. Many weeds are adapted to produce huge amounts of seeds, in some cases thousands of seeds per plant. This means if even a few plants escape control, they can contribute to future weed problems. In these cases, mortality by weed seed predators and pathogens can provide effective control of seeds that have already been shed, and can significantly reduce the number of seeds surviving in the soil to germinate in the future. Common seed predators in agriculture include birds, small rodents, and insects, such as ants, ground beetles, and crickets, which are all ubiquitous residents of agricultural fields. Other causes of mortality to weed seeds include infection by bacteria or fungi and desiccation from remaining on the soil surface. Agricultural practices that maintain stable habitats for seed predators have been shown to increase rates of seed predation. For example, the presence of cover crops and cover crop residue provides favorable habitat for seed-eating ground beetles. Reduced tillage practices can also increase rates of seed predation by minimizing disturbance of the habitat and by preventing seeds from being buried, where they would be safe from predation. Also, more diverse and varied agricultural landscapes can increase
seed predation by birds as well as insects. Organic farms typically support a greater abundance and diversity of seed predators than conventional farms.

Natural seed predation is known to reduce contributions to the standing seedbank, but developing specific recommendations for augmenting seed predation by natural populations of seed predators has been complicated by several factors. For example, some studies show that providing habitat refuges in the form of non-cropped buffer strips do not always result in increased rates of seed predator activity in the field, and in some cases may attract seed predators away from the field. Effective removal of weed seeds from the seed bank ultimately depends on seed predators being active at the time and place where the seeds are shed. Unlike herbivores, seed predators may not be able to follow chemical or visual cues to track food sources, and the foraging process may be more random. Many studies of seed predation have measured large amounts of variability in the rates of seed removal within individual fields, making it hard to generalize about factors that tend to increase predation rates. Quantifying the effect of seed predators in the field may be difficult since the rates of weed-seed removal may depend on species composition and density of weed seeds as well as seed predators; both of which can vary widely within a field and between seasons. These variations in rates of removal at shorter time scales and smaller spatial scales make it difficult to estimate the cumulative effects of seed predators on the seed bank. This is an active area of weed research, and future management recommendations for augmenting natural seed predation are promising for organic vegetable farming.

Soil-dwelling fungi and bacteria can cause significant mortality to weed seeds, even after they have been buried and are unavailable to seed predators. In some cases, pathogenic bacteria may be present in the seeds before they drop from the plant. In order cases, soil-borne bacteria may be able to follow chemical cues in the soil environment to migrate towards buried seeds. Some soil bacteria can also secrete chemicals that are toxic against weed seeds, acting like natural pre-emergent herbicides. Many weed seeds are protected from fungal or bacterial degradation by a hard seed coat, but any mechanical damage to that coat by seed-feeding insects or from heat or desiccation can make seeds more vulnerable to pathogens. In warmer climates, soil solarization can be used to directly destroy dormant seeds, and to increase the pathogenicity of soil microbes against seeds. Solarization involves using plastic covers to heat the soil to temperatures over 150 °F, which causes direct damage to seeds that are not heat-tolerant, and also increases the metabolic rate of soil microbes. There are few instances where soil microorganisms have been successfully applied as organic bioherbicides against weed seeds, due in part to species-specific pathogens that would be unable to control a diverse set of weed species. Organic vegetable production would be a likely target niche for any future bioherbicide innovation due to the high value of the crops and relatively few existing formulations on the market to compete with. Methods for conservation of existing soil microbes for control of weed seeds is an active area of research, and some results indicate that practices to promote soil health, such as cover cropping, reduced tillage, and crop rotation may help to manage beneficial soil-dwelling microbes.
Crop competitiveness. Crops and weeds directly compete with one another for resources such as sunlight, space, water, and nutrients. If the competitive ability of crops can be enhanced such that they acquire a greater proportion of the resources available in the field, then they may be able to suppress the growth of weeds, leading to lower establishment of weeds and lower production of weed seeds for future growing seasons. In many agricultural systems, water and nutrients are added through irrigation and fertilization to optimize plant growth and yield, and would therefore not be limiting factors for weed growth. Therefore, sunlight and space represent the resources that crops must exploit better than weeds in order to gain a competitive advantage. There is a wide range of competitive abilities between crop species, with few species being very good competitors against weeds. Within crop species, different cultivars may show variation in competitive ability against weeds, and those cultivars should be selected as a part of an IWM strategy. For example, it has been suggested that producers anticipating weed problems should select a pea cultivar with a long vine length within the appropriate market class as vine length is correlated with crop competitiveness. In modern conventional agriculture, the widespread use and high efficacy of herbicides has reduced the reliance on crops to have to outcompete weeds. This has led to modern cultivars being developed that often have reduced competitive ability as a tradeoff for increased yield. Chemical inputs to control weeds are often impractical or ineffective in organic agriculture, so being able to select crop varieties with the ability to suppress weed pests in the field is a valuable tool for organic farmers.

Many studies have shown that early season vigor is the most important characteristic for determining whether a crop cultivar will compete well against weed species. Rapid, early season growth allows the crop to take up water and nutrients, and more importantly to develop a canopy that takes up light and space before weeds have time to germinate and become established. Ensuring early season vigor in crops can be done in a variety of ways. The early portion of the growing season may have substantially cooler temperatures than later in the season. Selecting a cultivar that has rapid growth under cooler conditions may promote growth during the cooler period of the early season. Conversely, accurately timing planting to coincide with optimal conditions for the crop will ensure rapid, early growth. Ensuring optimal water and nutrients through irrigation and fertilization will help crops to develop rapidly. When possible, using transplants rather than direct-seeding vegetables can give crops a direct advantage over weeds as the crop has developed biomass before ever encountering weeds, and can therefore immediately begin to compete for resources. The period by which weed control must be carried out to prevent yield loss also known as the critical period of weed control (CPWC) is generally longer in direct-seeded than in transplanted crops. As a result, some crops that are direct-seeded as opposed to transplanted must receive weed control earlier during their cropping cycle and for a longer period of time following planting. Transplanting gives the crop a head-start against weeds when it comes to early season growth and competition for light and space.

In addition to vigorous, early season growth, there are other characteristics of crops that tend to make them more competitive against weeds. In general, taller, more erect plants are better at competing for light and space and will tend to shade out smaller plants around them. Plants that
develop a large, dense canopy, or have large leaf area also tend to compete well for light and will shade out weeds below them. However, for many crops, modern breeding programs select for plants with reduced vegetative growth in exchange for greater yields of seeds or fruits. Some plants, including some cereal crops are known to be able to suppress weed germination through defensive chemicals exuded through the roots, which is known as allelopathy. Developing varieties of crops with increased allelopathy is still in its infancy, and cultivars of vegetable crops have not yet been bred with increased allelopathic chemicals. However, allelopathic cultivars could provide a means of weed suppression for organic systems in the future. Crops will only be able to compete with weeds if they are healthy, so choosing varieties that are resistant to local pest and disease pressures will help to maintain the competitive ability of the crop over weeds. Any additional source of stress such as insect grazing, plant-parasitic nematodes, or fungal infection can be compounded by stress from weed pressure, and the combination could lead to crop failure, even if the crop could tolerate either stress on its own.

*Planting pattern.* Altering the spacing arrangement of crop plants can help to maximize the crop’s ability to take up resources and make them unavailable to weeds. Reduced row spacing and increased seeding density can help to maximize the area occupied by the crop and reduce areas where weeds can germinate and grow. Reducing the area of the inter-row space allows canopy closure by the crop to keep sunlight from reaching weeds within and between rows. Many studies show that reducing inter-row spacing to the same distance as the intra-row spacing can maximize weed suppression by the crop. This uniform planting pattern maximizes inter-specific competition between crop plants and weeds while minimizing intra-specific competition among crop plants. In addition to more canopy closure, more of the below-ground space is occupied by crop roots, allowing more of the water and nutrient resources to be taken up by the crop and possibly preventing germination of more weed seedlings. Increasing the seeding density can also help by producing more plants per unit of area. Increased crop density produces more crop plants to take up limited resources per unit of area, which keeps those resources from being used by weeds. Decreasing inter row distance and increasing seeding density effectively increase the leaf area index (LAI) of the crop, which is a measure of the area of available crop leaves per unit area of bare ground. At higher values of LAI, a greater proportion of sunlight is taken up by the crop, leaving less sunlight available to weeds.

There are some drawbacks to applying narrow row spacing and increased seeding rates in organic vegetables. Organic seeds can be very expensive, which may mean yield gains from increased weed suppression may not outweigh reductions in yield per plant that may occur at higher crop densities. In some cases, increased crop densities can increase the spread of disease, as plants are closer to one another and the microclimate of the crop is more homogeneous with narrow row spacing. Narrow row spacing may also prevent any rescue weed control through tillage if machinery cannot fit between rows. Narrow row spacing and increased crop density would also not work for vegetables where crowding causes a significant reduction in fruit size. This limits the applicability of this method for most vegetable crops, but could be applied in systems like sweet corn and vegetable bean crops, such as lima or snap beans. These methods
could also be applied to cover crops grown before or after vegetable crops for the purpose of suppressing weeds before or after the vegetable crop’s growing season.

The timing of planting can also be altered to ensure maximum competitive ability of crop plants by avoiding periods when problematic weeds are growing. Altering the planting date of a vegetable crop requires knowledge of what weed species are present in the field and what conditions favor the growth of those weeds. Planting dates can be shifted earlier or later to avoid periods where conditions would be more favorable to weed growth than crop growth. Weeds that germinate at the same time as the crop are typically better at competing for resources than weeds that germinate after the crop is established. If early season weeds would present a problem to a particular crop in a particular field then delaying planting time until later in the growing season allows weeds to be controlled by cultivation or herbicide application prior to crop planting. Planting later in the season could also allow faster growth for the crop in warmer soil and a reduced CPWC. If problematic weed species tend to germinate later in the season, then planting crops earlier may help to achieve canopy closure in the crop and a better competitive ability before those weeds have a chance to germinate. At that time the crop may be at a size where it is better able to compete with weeds and would not suffer any yield loss.

**Fertilizer.** Healthy, vigorous crops will compete better with weeds for resources. As such, cash crops should be supplied with adequate amounts of water and nutrients. When applied appropriately, these resources will only be accessible to the crop, and not weeds. Therefore, suitable amounts, placement, and timing of nutrient application in relation to the crop are important in assuring a competitive crop. This is because when located in the same area, weeds are usually more competitive than crops for nutrients. Broadcasting fertilizers (phosphorus and nitrogen) not only increases weed biomass but also enriches the weed seedbank when compared to subsurface application. This is because when broadcasting fertilizers, the entire field receives the application instead of just crop rows, which will more likely feed weeds. Addition of nitrogen fertilizer stimulates germination of dormant weed seeds, which encourages a new flush of weeds. Wise management of soil fertilizers is therefore crucial in reducing weed pressure in both short- and long-term scales. Avoiding pre-plant broadcasting of fast-releasing N fertilizers or controlling the resulting flush of weeds (such as stale seedbed techniques) before planting/transplanting cash crops would help to limit competition from the weed population.

One way to limit “feeding the weeds” is placing the fertilizer as close to the crop as possible so that it is more likely consumed by the crop. Banding fertilizers close to the crop row and applying it at the appropriate time enhances the crop’s accessibility to the fertilizer and avoids feeding weeds located between crop rows. Applying fertilizer below the soil surface (subsurface banding or injection) would further eliminate flushes of new weeds. Another method is to substitute N fertilizer with a legume green manure or other organic fertilizers. A study demonstrated that using crimson clover as a green manure has the potential to reduce the need for herbicide as well as N fertilizer applications in subsequent crops. However, in the aforesaid study, synthetic N fertilizer was used. Although crimson clover significantly reduced weed growth, it did not entirely eliminate weed interference with sweet corn growth, indicating that
this strategy should be used in conjunction with other weed management tools. Studies have demonstrated that in the long term, using organic N amendments reduces the weed seedbank when compared to continuous use of mineral N fertilizers.

**Mulching.** Mulching can be a handy practice for managing weeds. The underlying mechanism of weed suppression by mulching is to reduce light transmittance, which is more important than allelopathy (release of chemical to inhibit weed seed germination) or physical impedance. Besides infield crop residue, many materials can be used for mulching including natural products such as bark, straw, leaves, paper, and compost and synthetic plastic mulch. Natural mulches are not feasible for use over large acreage because of the difficulties of application but may work well in small, specialized farming situations. Natural mulches should be evenly spread and thick enough to prevent light from reaching the soil surface. Research suggests that organic mulches be at least 1.5 inches thick and heavy enough that they are not easily displaced by wind or water. Further, they should be free of weed seeds and other pests and should not cause specific problems such as attracting rodents and slugs. An additional benefit of some natural mulches is their ability to add organic matter to the soil.

Synthetic mulches may be more reliable for blocking weed establishment than natural mulches and provide other benefits such as conserving moisture, increasing soil temperature, and are easier to place over a large area. By increasing the soil temperature, they enhance early season growth of some warm-season crops such as solanaceous and cucurbitaceous crops. Weed seed germination and seedling growth can be suppressed at high soil temperatures through solarization. Clear plastic and UV-absorbing clear plastic can be used to raise soil temperatures to temperatures which are above the thermal death point for most weed seedlings. Clear plastic mulch decreased pigweed (*Amaranthus retroflexus*) populations within two weeks to less than 10% for one year, demonstrating the sensitivity of some annual weeds to solarization. Solarization has also been demonstrated to be effective for controlling yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*), which are difficult to control with conventional methods. In addition, solarization has been widely used to manage plant-parasitic nematodes in vegetable crops. A pitfall of using plastic mulches includes material expense, machinery, and energy input for layout and removal, labor cost, and problems of disposal after use. There are also problems of weeds growing in row middles between plastic beds and runoff during heavy periods of rainfall.

**Abrasive weeding.** Weed blasting is a newer weed management tactic where air-propelled abrasive grits are used to physically abrade and kill weeds. It was demonstrated that granulated walnut shells could be used to kill small lamb’s quarters (*Chenopodium album*) seedlings. Field research has shown the potential use granulated maize cobs to control small broadleaf weed seedlings within maize (*Zea mays*) and soybean (*Glycine max*) rows. Because this tactic indiscriminately abrades stem and leaf tissue of weeds and crops, the success of the tactic depends on a size differential between weeds and the crop. A field study was conducted to determine the effect of air-propelled abrasive grit type, including organic fertilizers, and application frequency on weed density and biomass in organic tomato (*Solanum lycopersicum*)
and pepper (*Capsicum annuum*) cropping systems. Abrasive-grits, including granulated walnuts shells and maize cobs, greensand fertilizer, and soybean meal, were applied via compressed air between one and four times within planting holes of plastic mulch. Two applications of abrasive grits, regardless of grit type, reduced weed density by 63% and 80% in tomato and pepper, respectively. Broadleaf weeds were more susceptible to abrasive-weeding than grass weeds. Abrasive-weeding reduced final weed biomass by 69-97% compared with the weedy control, regardless of grit type or application frequency.

**Herbicides and stale seed bed.** Organic farmers need new methods to improve weed management within crop rows. The potential use of natural products has received substantial interest. Products that are made through natural processes and have herbicidal properties are permissible for use in organic agriculture. Materials including vinegar, citric acid, and essential oils can supplement in-row hand weeding, cultivation, plastics, flame weeding, and other practices. There are practical limitations to the use of organic herbicides in vegetable crops. Organic herbicides are mostly nonselective products which means they can injure the exposed parts of cash crops and they can be too costly when broadcast at the rates necessary for adequate weed control. Thus, successful integration of natural products for weed control after the crop is planted will require development of application technologies that can minimize crop injury and lower usage volumes. Thus, when organic herbicides are used, one goal should be limiting the amount of treated area. If herbicide applications can be limited to a band within the crop row, herbicide use can be reduced by up to 75% or more compared to broadcast applications covering entire fields. Further, banding herbicides over crop rows optimizes their use compared to broadcasting it over the entire field. Weeds within the cropping row are then suppressed and another tactic such as the placement of straw, cover crop residue or growing a living mulch can be used to manage weeds between crop rows. Banding an application to target only in-row weeds could substantially reduce the volume of product used, while providing control where it is most needed.

The stale seedbed method, which is sometimes used in vegetable plantings, may be an ideal tactic to use in collaboration with organic herbicides. This method is executed by preparing a field and delaying crop planting (2-3 weeks) to allow weed flushes that can be killed just before planting. If killed with little soil disturbances (e.g., light cultivation, flaming, herbicide, etc.), the weed seedbank in the upper few centimeters of the soil will be depleted, restricting weeds in the ensuing crop. If time allows, this can be done two times prior to planting. This may be recommended for the slowest growing crops. An advantage of this method is that the crop emerges in a weed-free environment giving it a competitive edge over later-emerging weeds. In some instances, this technique may provide an opportunity for crop emergence and establishment before the next weed flush occurs. Despite use by some organic growers, this practice has received limited attention. However, research as shown that stale seedbed when used in combination with other weed management tactics has effectively reduced weed densities in peanuts, lettuce, snap beans, and cucumbers. If application of the stale seedbed method can limit
herbicide sprays to narrow strips within crop rows, this could result in significant savings while suppressing weeds in areas where it is most crucial.

A variety of organic-compliant techniques (flamer, rotary cultivator, rotary hoe, and top knives) may be used effectively to form stale seedbeds. Techniques that do not disturb the soil surface generally have fewer weeds germinating with the crop. The appropriate implement may vary between growers, and should be selected based on operating cost, on-farm availability, and efficacy. A more detail discussion of the stale seedbed technique can be found at (https://extension.umd.edu/learn/stale-seedbed-technique-relatively-underused-alternative-weed-management-tactic-vegetable).

**Summary**
Weeds are very well adapted to colonizing, reproducing, and surviving in agricultural fields. The goal of IWM is to keep weeds off-balance by making it hard for them to adapt to field conditions where multiple tools are being used to exploit their weak links. In this document, we introduced a number of concepts and tools that should be considered when devising an organic weed management program. Adapting truly IWM practices into vegetable production will allow for a more sustainable weed suppression program that limits reliance on any single management tactic like tillage. In addition, non-chemical weed control methods are now the subject of many research programs that strive towards overcoming this main challenge remaining in organic agriculture. As such, a conscious effort should be made to keep up with the latest research in which information can be used to help manage weeds organically. It is also highly recommended that organic producers conduct small on-farm experiments. This can be done by combining different types of weed management tactics and comparing them with current weed management practices. This will allow producers to see first-hand which practices are most ideal for managing weeds according to their field environment.

**Acknowledgements**
This extension article was supported by a USDA NIFA EIPM (2014-70006-22551) and USDA NIFA AFRI CARE (2016-68008-25079) grant.
References


Major, J., C. Steiner, A. Ditommaso, N. P. S. Falcao, and J. Lehmann. 2005. Weed composition and cover after three years of soil fertility management in the central Brazilian Amazon:
Compost, fertilizer, manure and charcoal applications. Weed Biology and Management 5: 69-76.