Weed management in organic vegetable production

A PRACTICAL REVIEW OF APPLIED RESEARCH

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Foreword

The intention of this manual is to provide an objective analysis of organic weed management strategies. One that is based on peer-reviewed and published applied research. The strategies used in organic weed control have been around, in most cases, for centuries, and therefore current peer-reviewed research is often not discussed when weighing management options. With this in mind, the research is first objectively summarized for those who are interested in “just the facts,” the background information is presented in more detail, and finally the research that serves as the basis for the summary is reviewed.

The strategies approved for use in organic production by the United States Department of Agriculture (USDA) National Organic Program, local organic grower organizations, and end-users change periodically. Consult the appropriate organizations for approved strategies and products prior to any use, as well as labels and registration status for products used as herbicides.

How to use this manual:

- **Interested in just the facts?** Focus on the key points and background information for practical guidance and an overview of weed management options.

- **Interested in the details and evaluation of options?** Consider also reading the research sections for an overview of recent peer-reviewed studies conducted on vegetables.

Few things are harder to put up with than the annoyance of a good example.

*Mark Twain*
Problem avoidance: Preventive strategies

By far, the best management strategy for any weed is to prevent introduction and dispersal. There are several routes for weed introduction, and the majority involve inadvertent grower actions. Potential sources of weed seed on the farm include compost, manure, mulches such as straw, equipment, open irrigation water, and contaminants in crop seed and transplant containers. Occasionally, new invasive weeds are intentionally planted, as is the case with kudzu, which was first marketed for forage and erosion control in the southeastern United States, and velvetleaf, which was initially cultivated as a source of fiber for cloth and rope.

Consider all potential entry routes for new weed species and methods to reduce weed seed and vegetative propagule introduction and viability. Weed seed in compost, for example, can often be destroyed by prolonged heat and adequate moisture in the pile. Some weed seeds such as curly dock can pass through the digestive tracts of cows and other farm animals.

Consider the source of all compost, manure, and straw, and question providers about weed contamination prior to purchasing. For example, was a hay field weedy, and if so, when was the field harvested relative to weed flowering? Were perennial weeds present that could be dispersed through root cuttings? Cultivators, harvesters, and other field equipment are sources of vegetative root tissue and seed for many weed species and should be cleaned of soil and vegetation before being moved between fields.

Historically, many weed species have been introduced as a seed contaminant in crop seed. This source of weeds is particularly prevalent when “saved” seed is replanted in the following year or on another farm without cleaning or analysis by a seed certification agency.

Prevention is also important in minimizing the spread of weed species already found on the farm. Management practices that minimize weed seed production are important in fields after crop harvest and in surrounding field margins, such as:

- Till or mow after crop harvest but before weeds go to seed.
- Identify weeds prior to using tillage for weed management—perennial species can be spread by cutting below-ground vegetative tissue, such as rhizomes and roots.
- In field margins, consider planting and managing a boundary strip that is kept free of weed seed production. The planted species could include a mix of those that are competitive with weeds and support beneficial wildlife or predators of other agricultural pests. Field margin plantings might also be harvested for hay.
- Prevent weed seed production along irrigation canals, reservoirs, and other open water sources.
Research

Manure composting to reduce weed seed viability

Summary: Manure was composted in a windrow with a core temperature of 130°–150°F. After 2 weeks of composting, the high temperatures killed 100% of the seed of green foxtail, catchweed bedstraw, kochia, wild buckwheat, field pennycress, and pineappleweed, and all but 3.5% of the seed of redroot pigweed. No seeds survived after 4 weeks of composting. This study demonstrated the effectiveness of even short periods of composting at eliminating the distribution of viable weed seeds.

Weed seed longevity

Summary: This study examined the long-term survival of weed seeds and reveals the importance of preventing weeds from becoming established. Weed seeds were buried and then dug up and tested annually to see if they would germinate. Following 17 years of deep burial without tillage, seed of 4% of annual grasses, 11% of annual broadleaf weeds, 30% of biennial weeds, and 8% of perennial weeds germinated (table 1). Common mullein proved to have superior longevity, with 95% of the seed germinating at the end of the study.

Table 1. Germination of selected weed species after 17 years of burial in Nebraska.

<table>
<thead>
<tr>
<th>Species</th>
<th>Germination, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnyardgrass</td>
<td>0</td>
</tr>
<tr>
<td>Green foxtail</td>
<td>0</td>
</tr>
<tr>
<td>Longspine sandbur</td>
<td>0</td>
</tr>
<tr>
<td>Yellow foxtail</td>
<td>0</td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>7</td>
</tr>
<tr>
<td>Hairy nightshade</td>
<td>65</td>
</tr>
<tr>
<td>Jimsonweed</td>
<td>90</td>
</tr>
<tr>
<td>Redroot pigweed</td>
<td>1</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>35</td>
</tr>
<tr>
<td>Canada thistle</td>
<td>7</td>
</tr>
<tr>
<td>Common mullein</td>
<td>95</td>
</tr>
<tr>
<td>Curly dock</td>
<td>61</td>
</tr>
<tr>
<td>Dandelion</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Adapted from Burnside et al. 1996.

Open irrigation water as a source of weed seed

Summary: Irrigation channels were sampled at three depths and weed seed germination was tested in controlled conditions. Seed from 23 families and 63 species germinated, primarily from the Asteraceae and Poaceae families. Common species included Conyza spp., annual sowthistle, smooth pigweed, Bromus spp., and annual bluegrass.

Planted field margin boundary strips for weed control

Summary: Boundary strips planted with grass and wildflower seed mixtures were compared to unplanted strips surrounding agricultural fields. The planted strips limited movement of weeds including Canada thistle, catchweed bedstraw, poverty brome, and quackgrass into the fields.
Managing the weed seedbank

The soil contains millions of weed seeds and serves as a seedbank or reservoir for future weed infestations. Many of these seeds are dormant, and will not germinate until triggered by environmental or physiological signals. Although seeds can remain dormant for several years, weed pressure during the cropping season can be reduced through practices that deplete those seeds that will readily germinate before crop planting.

There are two techniques for depleting weed seeds. The first, known as the stale seedbed technique, where soil is tilled 20 to 30 days before crop planting. Weeds that germinate during the delay period are killed shortly before seeding using flaming, mowing, or shallow tillage.

Solarization is the practice of covering soil with plastic mulch for several weeks in the summer to kill plants. After the plastic is removed, crops are planted or the ground is left fallow.

Additional tillage into a seedbed that has been depleted of germinable weeds. This technique is particularly useful with small-seeded or slow-growing crops that are not very competitive with weeds, such as onions and carrots.

The second technique, solarization, uses sheets of clear plastic mulch to cover the soil and trap solar energy near the soil surface. Intense heat and sunlight are required for effective solarization, thus limiting the use of this strategy in more temperate production areas. Moist soil conducts heat better than dry soil and promotes microbial activity. After about 4 weeks of solarization, the plastic mulch is removed and the crop is planted or the ground is left fallow until the next growing season. Solarization is effective at killing annual grass and broadleaf weeds near the soil surface, but is less effective with large-seeded and perennial weed species that are capable of emerging from lower depths. The length of solarization directly determines the degree of weed seed depletion.
Research

**Stale seedbed: Technique comparison**


**Summary:** The authors examined the effectiveness of various stale seedbed techniques. Flaming reduced the number of annual broadleaf weed species, while yellow nutsedge control was poor. A single flaming after a 24- to 28-day stale seedbed delay period was as effective as multiple flame treatments during the period between seedbed preparation and crop planting. Using a flexible tine weeder at the end of the delay period did not control established weeds, and heavier cultivation using a spring-tooth weeder stimulated further weed germination.

**Stale seedbed: Timing of seedbed preparation prior to crop planting**


**Summary:** Stale seedbeds were prepared 40, 30, 20, and 10 days before cucumber planting and were compared against a control seedbed prepared on the day of planting. Weeds were killed at the time of crop planting using herbicides. Weed biomass at planting was greatest in the seedbed prepared 40 days earlier and cucumber yield was reduced. Seedbeds prepared 10 to 30 days before planting had higher cucumber yields than the seedbed prepared on the day of planting. Optimum seedbed preparation was 20 to 30 days before planting. The authors concluded that a properly managed seedbed improved in-season weed control while increasing crop yield.

**Soil solarization**


**Summary:** Researchers compared the effect of soil solarization using polyethylene film for 3, 6, and 9 weeks on weed populations and carrot yield. Soil temperature was about 50°F greater at a 2-inch depth in solarized soils. Weed biomass and density were reduced following solarization for about half of the tested species. Seed germination of one weed species, Benghal dayflower (*Commelina benghalensis*), was increased by solarization. When soil was solarized for 3 to 9 weeks, carrot yield and weed control were greater than in the non-solarized control plot.


**Summary:** Soil was solarized with clear polyethylene film for 8 weeks prior to planting lettuce and onion. In lettuce, solarization eliminated all but 2 of the 14 weed species; in onion, solarization reduced the number of weed species from 7 to 4. While solarization reduced weed cover, further weed management was necessary during the crop season.
Both living and non-living mulches can be useful for weed suppression. The basic objective of weed management with mulches is to deprive emerging weeds of light. Mulch is most commonly used with transplanted annual vegetables or with perennial crops such as berries where the crop is larger than seedling weeds. Researchers have tested a variety of materials, both natural and synthetic, for their value as mulch ground covers. Polyethylene or plastic is the most common synthetic mulch. Weed management with plastic is often excellent, with the exception of the hole in which the crop plant is transplanted. Dark plastic mulches raise soil temperatures early in the season, which helps promote crop growth and earlier maturity.

The drawback to plastic is that the mulch needs to be removed at the end of the crop season, and often cannot be reused. Degradable plastic mulches have been developed but are not widely used because the rate of degradation is difficult to manage—the mulch needs to last long enough for efficient weed control, yet degrade fast enough so that it doesn’t need to be pulled and disposed of at the end of the growing season.

Natural mulch products, by contrast, can be used to suppress weeds, while contributing organic matter to soil without the need for disposal at the end of the crop season. Natural mulch products used in vegetable production include wood chips and pine needles, paper and cardboard products, yard waste and leaf debris, and straw. While weed suppression is often equal to or greater than that with plastic mulch, natural products can also serve as sources of pathogens and as refuge for pests such as rodents and insects. Additionally, natural mulches can alter soil properties as they degrade in soil. For example, mulches can alter soil pH or temporarily reduce the supply of nitrogen to the point where it affects plant growth. Despite these drawbacks, natural mulches can be very useful in suppressing weeds with minimal environmental impact.

The strategy for using living mulches (also known as intercropping, interseeding, and strip-mulching) is to plant a cover crop that will out-compete weeds while not interfering with crop growth and yield. This fine line between weed suppression and crop suppression by living mulches has limited practical applications in many cases. Living mulches have been very successful in long-term perennial crops, such as tree and bramble fruit production, where the crop has a distinct age and size advantage over the mulch. For small crops, though, the living mulch can become the crop’s worst enemy as they jointly compete for water, light, and nutrients. Living mulch research has included several grasses, such as rye, and legumes, including alfalfa and clover species.

In addition to competing with the main crop, living mulches can also serve as a refuge for pathogens, insects, and rodents. Further research is necessary to refine the practical use of living mulches for weed suppression without also suppressing crop growth.
**Research**

**Comparison of paper and polyethylene mulches**


**Summary:** Lettuce yield was up to 25% greater when grown with paper or polyethylene mulch compared to lettuce grown with no mulch. Yields were similar for both mulch types. In the cooler of two evaluation years, air and soil temperatures were highest under the polyethylene mulch and lowest in the non-mulched treatment. The authors note the advantage of paper degradation at the end of the growing season.

**Comparison of organic, plastic, and paper mulches**


**Summary:** This study evaluated four types of mulches on tomatoes. Hay mulch applied to a depth of 4 inches several weeks after tomato planting suppressed annual weeds. Adding two layers of newsprint below the hay enhanced weed control. By contrast, composted yard waste (1.2 to 2 inches in depth) was less effective than hay in suppressing weeds. Paper mulches decomposed during the crop season, allowing weed growth to occur before harvest. Labor costs were higher for plastic mulch than for hay mulch due to the time spent removing the plastic at the end of the season.

**Winter rye as a living mulch in broccoli**


**Summary:** This study demonstrates the fine line between suppressing weeds and suppressing the crop. Rye interseeded at the same time as broccoli transplanting reduced weed growth, but also reduced crop yield compared to the weed-free treatment. Interseeding 10 and 20 days after transplanting did not lower broccoli yield, but they also failed to suppress weeds.

**Clover and perennial ryegrass as living mulches in asparagus**


**Summary:** Perennial ryegrass, white clover, and a mixture of the two species were evaluated as living mulches in asparagus production. Weed control was greatest where white clover or the living mulch mix was grown. However, the living mulches reduced asparagus fern growth by 50% the first year. In the second year, asparagus fern growth reduction ranged from 25% (white clover and mulch mixes) to 50% (perennial ryegrass).

**Legumes as living mulches in sweet corn**


**Summary:** White clover, red clover, and alfalfa were planted in fall, and sweet corn was planted without tillage into the intercrops the following spring. While all three legumes suppressed weeds, only white clover succeeded at not limiting corn growth or yield. Red clover and alfalfa were too competitive, affecting corn plant size and reducing yield.
Allelopathy is defined as the effect of one plant on another through the release of a chemical compound into the environment. Allelopathic compounds are often considered “nature’s herbicides,” and can be produced by both crops and weeds.

Allelopathic cover crops have been used with mixed success to suppress weed growth in the following crop season. Allelopathic cover crops can also be used to suppress nematodes and pathogens.

Rye, oat, and mustard species are commonly planted as cover crops for allelopathic weed control. This strategy can be an important component of an integrated weed management system.

The observation of allelopathic plant suppression is not new. Theophrastus observed that chickpea reduced nearby weed growth as early as 300 B.C., and Plinus Secundus (1 A.D.) reported that grain was “scorched” by chickpea, barley, and bitter vetch. Still, there have been relatively few effective demonstrations that have led to reliable uses in agricultural pest management.

Many crop and weed species have been observed to have allelopathic properties (table 2). Over 240 weed species have been reported to be allelopathic to other nearby plants of the same species (autotoxicity) or other crop and weed species. The use of allelopathy to favor the crop over weeds has been investigated in three aspects: (1) as an allelopathic winter cover crop that suppresses weeds before the cropping season; (2) as a living mulch during the cropping season to reduce weed interference; and (3) as an isolated compound from an allelopathic plant, applied as a herbicide.

Table 2. Selected common crops and weeds with reported allelopathic properties.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Weeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>alfalfa</td>
<td>Canada thistle</td>
</tr>
<tr>
<td>asparagus</td>
<td>cocklebur</td>
</tr>
<tr>
<td>barley</td>
<td>common lambsquarters</td>
</tr>
<tr>
<td>bean</td>
<td>field bindweed</td>
</tr>
<tr>
<td>beet</td>
<td>foxtail sp.</td>
</tr>
<tr>
<td>broccoli</td>
<td>jimsonweed</td>
</tr>
<tr>
<td>cabbage</td>
<td>kochia</td>
</tr>
<tr>
<td>clover</td>
<td>pigweed sp.</td>
</tr>
<tr>
<td>corn</td>
<td>quackgrass</td>
</tr>
<tr>
<td>cucumber</td>
<td>ragweed sp.</td>
</tr>
<tr>
<td>oat</td>
<td>smartweed sp.</td>
</tr>
<tr>
<td>pea</td>
<td>velvetleaf</td>
</tr>
<tr>
<td>potato</td>
<td>wild mustard</td>
</tr>
<tr>
<td>rapeseed</td>
<td>wild oat</td>
</tr>
<tr>
<td>rice</td>
<td>yellow nutsedge</td>
</tr>
<tr>
<td>rye</td>
<td></td>
</tr>
<tr>
<td>soybean</td>
<td></td>
</tr>
<tr>
<td>sunflower</td>
<td></td>
</tr>
<tr>
<td>tomato</td>
<td></td>
</tr>
<tr>
<td>wheat</td>
<td></td>
</tr>
</tbody>
</table>
cide. To date, the use of allelopathic cover crops such as rye and oat, has had the greatest success.

The effect of allelopathic crops on weed growth has been very difficult to quantify. Weed suppression by neighboring plants is a combination of allelopathy and physical interference. Physical interference includes competition for light, water, nutrients, and other resource by the cover crop residue or living mulch. Allelopathic compounds are often complex and short-lived, and therefore are difficult to isolate and identify. Research conducted in greenhouses often doesn’t account for the effect of microorganisms, climate, and soil type, and thus often exaggerates the potential weed suppression compared to field conditions. In field research, the effect of physical interference is difficult to separate from allelopathy. Other factors that cloud evaluation of the impact of allelopathic cover crops on weed species include timing, growth stage, soil type, and climatic conditions during growth of the cover crop.

**Research**

**Rye residue for weed suppression**


**Summary:** Rye residue reduced emergence of green foxtail by 80%, redroot pigweed by 95%, common ragweed by 43%, and common purslane by 100%. Rye residue had no effect on yellow foxtail emergence.

**Oat allelopathy differs among crop cultivars**


**Summary:** Most of the oat cultivars tested (20 of 24) reduced common lambsquarters germination, but the amount ranged from 10% to 86% among cultivars. Several cultivars also reduced pea germination, indicating that selectivity in suppression between the crop and weeds may be difficult.

**Physical suppression versus allelopathy**


**Summary:** To find out how large a role allelopathic compounds play in weed suppression, the authors compared barley and rye residue with the compounds present and with the compounds leached (removed) from the residue. For rye, reductions in yellow foxtail emergence were attributed to physical suppression alone. For barley, a combination of physical suppression and allelopathy interacted to reduce yellow foxtail emergence by 81%.

**Allelopathic compounds isolated from turnip-rape**


**Summary:** The authors reported that isolated allelopathic compounds from turnip-rape plants suppressed several weed species, including smooth pigweed, spiny sowthistle, and barnyardgrass. Six different allelopathic compounds were isolated from all parts of the turnip-rape plant, although these compounds were very short-lived when incorporated in soil.
Reduced tillage and dark cultivation

Spring tillage stimulates weed seed germination and a flush of weed growth. Two strategies have been evaluated with the goal of reducing spring weed growth—reduced tillage and dark cultivation.

Reduced tillage

Three methods of reduced tillage have been evaluated for weed management in vegetable production:

- **In no-till production**, crops are planted without any primary tillage. Annual weed emergence is often reduced by the lack of soil disturbance. Continuous no-till production can lead to a shift in weed species that favors biennial and perennial weeds. No-till planting requires specialized equipment and more power to penetrate hard soil.

- **Strip-till planting** disturbs soil only in the rows in which the crop is planted. Strip-tillage is often conducted with a narrow rototiller and allows for greater and more consistent crop emergence than with no-till planting, particularly on hard or crusted soils. The area between planted rows remains untilled, inhibiting emergence of annual weeds. Weed pressure, however, is often greater within the tilled and planted crop row.

- **Punch planting** attempts to reduce the weed infestations common within the row in strip-tillage by disturbing the soil only in an area small enough to plant the crop seed. In small-seeded crops such as red beet, the punch plant hole is as small as 1/4 inch in diameter. The crop seed is dropped in the punched hole and the area between holes within the crop row remains undisturbed. Punch planting was researched thoroughly in the 1960s as a method for precision planting and has received renewed interest as a no-till planting strategy that allows for good soil-to-seed contact with minimal soil disturbance in the crop row.

Tillage often exposes many weed seeds to light and moisture, triggering germination. Reducing soil tillage can reduce germination of some weed species. Conversely, continuous reduced tillage production systems favor shifts toward perennial weed species.

Annual vegetable crops can be difficult to establish without some soil tillage. With this in mind, strip tillage and punch planting systems both allow planting with limited soil disturbance. The drawback is that weed germination will also be promoted within the disturbed area directly around the crop.

Some weed species require light for germination. To prevent exposure, tilling at night or shielding the soil during planting has been proposed as a way to reduce weed populations. Research results have been very mixed and the practical utility of such a strategy has been limited.
Dark cultivation

The germination of several weed species is promoted by light. For some species, only a brief flash of light is needed to trigger germination. Soil tillage in complete darkness has been proposed and investigated as a method to reduce germination of light-stimulated weeds. Results have been very mixed. Not all species require light to stimulate germination. Even when tillage is conducted in the dark, weed seeds end up close enough to the soil surface that sufficient quantity and quality of light triggers germination. Additionally, many other cues can stimulate weed seed germination, such as lack of dormancy and sufficient soil moisture, all of which confound results of dark tillage research. In summary, dark tillage can at best reduce subsequent weed pressure, but it is not consistent enough to be dependable as a major strategy for weed management.

Research

No-till vegetable production


Summary: Vegetable crops no-till planted into cover crop residues were compared with conventional tillage that incorporated cover crops. No-till production reduced emergence rates of hairy nightshade and Powell amaranth by 99% and 87%, respectively (figure 1).

Night tillage


Summary: Night tillage (plowing and disking) was compared to tillage during the day in a 3-year study. The effect of light on weed germination was more important in disking than plowing. When disking was conducted at night, only pigweed species and giant foxtail were affected; all other weed species were unaffected by the absence of light. The authors concluded that night tillage was not a reliable weed management strategy due to the variable and inconsistent results.

Punch planting


Summary: Punch planting plus flame weeding reduced overall weed density by 30% compared to conventional planting plus flame weeding. When punch planting and flame weeding were combined with delayed planting (stale seedbed technique), the effect was intensified considerably. This study demonstrates the advantages of integrating multiple strategies for weed management.
Thermal weed management

Intensive heat breaks plant cell membranes, leading to plant death when damage is extensive. The use of heat for weed control has been explored with flaming and steam or hot water treatments.

Flame weeding involves the use of a bank of burners at temperatures of 1500° to 1800°F, usually fueled with propane, that are pulled through the field. This technique can be used with stale seedbeds where weeds are flamed shortly before crop planting, after crop planting but before crop emergence, or after emergence of tolerant crops such as corn. Flaming is most effective on emerged annual broadleaf species with growing points that are not protected by the soil or by vegetation. Annual broadleaf species such as common lambsquarters, red-root pigweed, chickweed, and common groundsel are effectively controlled by flaming when weeds are young and succulent. Larger, established annual weeds, perennial weeds, and grasses often survive flame treatments. The intensity of flaming and dose (calculated in terms of fuel burned per unit area) are controlled primarily by ground speed. The dose required for optimum weed control increases with weed size, therefore early-season flaming is critical to its practical use. In sensitive crops where the growing point is exposed, selective flaming is possible only with shielded burners that protect the crop. In-row weed control is poor when burners shield the crop row. Fuel costs often limit the economical use of flame weeding on an extensive basis.

Hot water and steam have also been used to break weed cell walls, disrupting normal plant growth and sometimes causing plant death. As with flame weeding, early postemergence applications are more effective and require less energy than applications at later growth stages. Broadleaf annual weeds are more effectively controlled than perennial and grass species. While hot water and steam can effectively control some weed species, practical applications in agriculture are limited by the cost of energy required to heat water. Additionally, the safety of using steam under pressure should be considered by the applicator.

Research
Flame weeding: Weed species and growth stage


Summary: Plant size and species determined the degree of control with flaming. Species such as common lambsquarters and common chickweed with up to four leaves were completely killed. Larger weeds required a significantly higher dose of heat than smaller weeds to achieve 95% control. Shepherd’s purse has a protected growing point and re-grew after flaming. Annual bluegrass was not controlled at any growth stage or flaming dose.
Weed control by flaming and hot steam in apple orchards


**Summary:** Flaming gave poor control of perennial weed species. Multiple treatments were more effective than single treatments, particularly for more tolerant species and at later weed growth stages. Hot steam treatment did not effectively control weeds.

Flame weeding in organic onions and carrots


**Summary:** Flame weeding was more efficient and less labor intensive than hand weeding. Two flame applications in onions were efficient in terms of labor but reduced crop yield. In carrots, the combination of a single flame weeding and hand weeding reduced labor costs compared to hand weeding alone, although pre-emergence flame weeding slightly reduced crop yield.

Soil steaming


**Summary:** Steam applications to bring the soil temperature to 142°F and 160°F reduced weed emergence by 90% and 99%, respectively. However, the researchers concluded that the high energy consumption and time required for the weed control operation limit practical applications.

Steam application: Weed species response and steam rate


**Summary:** Steam application rate was critical for weed control. Steam applied at 2,850 lb/a reduced weed growth, but application at 1,400 lb/a did not. Common lambsquarters and redroot pigweed control was greater than 90% when steam was applied at the higher rate. Emergence of several broadleaf weed species was not affected by steam application.

Hot water weed control


**Summary:** The authors evaluated effectiveness of hot water for weed control, measured as a 90% reduction in weed weight. Treating weeds at the six-leaf stage required three times more energy than applications made at the two-leaf stage. The earlier treatment reduced energy costs while increasing application ground speed. The amount of energy used was directly related to the duration of weed control. In general, a second treatment was required 25 days after the original hot water treatment for effective weed control. Perennial weeds regrew after treatment.
Development of “natural” herbicides has been relatively limited. Corn gluten meal and other “meals” made from plants have been used for weed control with varying results. Use of corn gluten meal as a herbicide was discovered accidentally by researchers investigating turf diseases. Corn gluten is a naturally occurring protein product of corn wet milling and is often used as a protein source in animal feed. It has about 10% nitrogen content.

Corn gluten must be applied before weed emergence (preemergence) as it has no effect on emerged or established weeds. The nitrogen in corn gluten can actually stimulate growth of established weeds or crops. Corn gluten inhibits root growth after seed germination, leading to plant moisture stress. However, with sufficient moisture, seedlings can overcome the inhibitory effects of corn gluten. Selected broadleaf and grass weeds are listed as controlled on product labels.

Corn gluten is non-selective as a herbicide—it will injure or inhibit early root growth of both weed and crop species. Therefore, it is not appropriate for direct-seeded crops after planting but before the crop is emerged. Weed control results have been variable when corn gluten is used in vegetable and fruit production systems.

Research

Corn gluten: Weed control in strawberry


Summary: This 4-year study found that grass weeds were not affected by corn gluten meal during any of the trial years. Results were mixed for broadleaf weeds: While July applications of corn gluten meal reduced the number of broadleaf weeds during 2 of the 4 years, the same treatment significantly boosted weed growth in comparison to the control—by 133% and 12%—during the other 2 years.
**Corn gluten: Application rate in strawberry**


**Summary:** Weed control varied by corn gluten meal application rate and timing. Broadleaf and grass weed cover and number were not reduced when corn gluten meal was applied in July, but an August application reduced weed cover and broadleaf weed number. Weed cover following an August application was reduced 30%, 33%, and 53% compared to the untreated control when corn gluten was applied at 891, 1,783, and 2,674 lb/a.

**Corn gluten: Weed control in vegetables**


**Summary:** Corn gluten meal was incorporated prior to planting vegetable crops. An application of corn gluten meal at 3,564 lb/a reduced weed cover by up to 82% as compared to the untreated control. However, corn gluten meal rates as low as 891 lb/a reduced survival of onion, red beet, radish, bean, carrot, pea, and lettuce seedlings by 35% to 73%. The authors concluded that corn gluten meal should not be incorporated prior to direct-seeding vegetables.

**Clove oil as a herbicide**


**Summary:** Several plant-derived oils were screened for potential herbicidal activity in laboratory and greenhouse studies. Johnsongrass, common lambsquarters, and common ragweed plants treated with clove oil were injured as early as 1 hour after treatment, and oil concentrations of 5 to 10% killed most weeds 7 days after treatment. By 30 days after treatment, some common ragweed plants displayed regrowth, and the author suggests that re-treatment and thorough plant coverage may be necessary for optimum weed control.
Crop competition for weed control

The ability of a crop to successfully compete against weeds reflects a combination of crop suppression of nearby weeds and tolerance of weed interference. For a crop to suppress weeds, it must outcompete nearby weeds for limiting resources such as light, water, and nutrients. The following strategies have been designed to favor the crop over weeds:

- Some crop cultivars are more competitive than others. Competitive cultivars typically emerge soon after planting, grow rapidly early in the season, and have a large leaf area and tall stature that shades nearby weeds. Choosing cultivars that mature quickly also allows for aggressive post-harvest weed management with mowing or tillage before weeds reproduce.
- Altering crop row spacing and plant density within the row can be used to close the canopy earlier, thus limiting resources (primarily light) available to weeds.
- Fertilizer and irrigation water can be targeted to favor the crop while restricting access to weeds. Banding fertilizer, for example, near the crop row favors access by the crop over a broadcast application over the entire field. Drip irrigation can also reduce weed growth by directing water to support crop growth while the areas between the crop row remain dry.

Research

Corn population and velvetleaf competition


Summary: Velvetleaf response to three corn populations (1x, 1.5x, and 2x of normal population) was determined. Velvetleaf emergence timing was compared to corn emergence. When velvetleaf emerged at the same time as corn, velvetleaf seed production was reduced 69 to 94% at the 1.5x corn population and 99% at the 2x corn population when compared to the conventional 1x population. Velvetleaf seed production was minimal when emergence was delayed, and the authors attributed reduced weed seed production to corn competition for light with the shorter velvetleaf below the crop canopy.
Snap bean row spacing and weed competition


Summary: Snap bean row spacings of 6, 10, 14, 18, and 36 inches were compared while keeping total plant population per area constant (beans were spaced farther apart within the row in the narrower row spacings). Narrow-row snap beans closed canopy earlier than wider-row snap beans, reducing weed growth. Row spacings of 6 to 14 inches reduced weed growth by 18% when weeds emerged with beans and by 82% compared to 36 inch row spacing when beans were kept weed free for the first half of the crop season.

Bean cultivar choice and row spacing affects weed growth


Summary: Three bean cultivars were compared at three row spacings. Cultivars OAC Gryphon and OAC Laser reduced weed biomass (weight) by 10 to 35% compared to OAC Sprint (figure 2). Narrower row spacings reduced weed biomass further. Neither row spacing nor cultivar choice altered weed density, although weed biomass decreased as crop size and density (bean leaf area index) increased.

Figure 2. The effect of bean cultivar on total weed biomass, quantified at the R-9 bean growth stage, at Elora, Ontario in 2 years. Adapted from Malik et al. 1993.
Cultivation serves as the main form of weed control in most organic vegetable crops. Many different types of cultivation implementations have been developed to control weeds in and/or between the crop rows. The necessity for reliable mechanical weed control has led to the development of many innovative cultivators. This review focuses on some of the more commonly used tools for in- and between-row weed control.

In-row cultivators

Mechanical weeding within the crop row requires selectivity between the crop and weeds, and can be a difficult proposition given that both are often at similar growth stages at the time of cultivation. In-row weeder requires very precise operation and are often operated at slow speeds with narrow (one or two crop row) equipment. Weed control is greatest when weeds are very small—often with two leaves or less. These tools usually need to be combined with more aggressive between-row cultivators.

The finger weeder includes three sets of ground-driven rotating fingers that pull soil and weeds away from the crop row and then push a shallow layer of soil back over the crop row to cover small weeds. This precise, lightweight tool is often belly-mounted on a small tractor with the operator sitting over the crop row to guide the implement.

The torsion or rod weeder is a very simple, affordable design consisting of two steel rods, one on each side of the crop row to uproot small weeds while pushing soil into the row. The torsion weeder is very effective in controlling small in-row weeds. This tool can be combined with an existing between-row cultivator for improved in-row weed control. The distance between the rods and the cultivated crop can be easily adjusted based on the desired precision and growth stage of the crop and weeds.

Between-row cultivators

Several implement designs are effective at controlling weeds between the crop rows, ranging from traditional S-tine cultivators to more innovative brush hoes. This review focuses on the spider gang or rolling cultivator, the basket weeder, and the brush hoe.
Spider gang or rolling cultivators use toothed “wheels” that rotate vertically across the ground. The wheels are angled to uproot weeds between the crop row while throwing a small amount of soil over weeds within the crop row. Wheel angle is easily adjusted based on the crop and weed growth stage and the desired cultivation aggressiveness. This implement can be operated at fairly high ground speeds, but can occasionally become plugged with plant residue.

The basket weeder consists of a series of rolling wire baskets with space between the baskets to accommodate the crop row. Minimal soil is pushed into the crop row. This cultivator effectively controls small weeds, but does not perform well on crusted or high-residue soils.

The brush hoe is best described as a combination of a street sweeper and a hook-and-ladder fire truck. A series of brushes, similar in appearance to those on a street sweeper, are mounted on a horizontal axle. The PTO-driven brushes rapidly rotate and rip weeds from the soil, while the crop is protected by shields mounted between the brush units. Soil is pushed under the shields, covering small weeds within the crop row. The brush hoe is very aggressive and precise, often requiring two operators—one to drive the tractor, the other to steer the shields over the crop row. The brush hoe can remove fairly established weeds and provide some residual weed control by creating a dust layer that reduces further weed germination. Due to their high purchase cost relative to other cultivators, brush hoes are perhaps best suited for use on high-value crops.

Broadcast cultivators

In- and between-row cultivators have been used for many years in wheat, oat, and other agronomic crops and they’ve become increasingly common in vegetable production. Flex-tine cultivators use a series of flexible tines mounted in overlapping rows. Vibrating as they drag through soil, ripping out small weeds. These tools are most effective when weeds are in the “white thread” stage (single white roots are visible on weeds when soil is disturbed, often before leaf appearance). Established weeds and grasses at any stage are often not controlled. Conversely, the crop needs to be better established or at a later stage of growth to allow selectivity in removing smaller weeds. Lightweight flex-tine cultivators can be operated at high speeds and with varying tine intensity based on the crop growth stage.
Research

Mechanical cultivation in broccoli, sweet corn, and snap beans


Summary: Five cultivation implements were compared: flat and round flex-tine harrows, a spider gang cultivator, a brush hoe, and a conventional shovel cultivator. Weed control and crop yield were similar among implements in transplanted broccoli, largely because of the short crop season. In snap bean, weed control was greatest where early-season flex-tine harrowing was followed by either a shovel cultivation or brush hoeing. When used individually, weed control was greatest with the brush hoe, spider cultivator, or shovel cultivator (figure 3). The brush hoe provided some residual and in-row weed control in all crops. Weed management with cultivation alone was most difficult in sweet corn, given the crop’s limited ability to compete with weeds early in the season and the long crop season.

Carrot tolerance of between-row cultivators


Summary: A conventional cultivator was compared with a brush hoe at two cultivation distances from the crop row leaving the untilled strips of 5 and 10 cm. Carrot yields were not affected by type of cultivator or width of the untilled strip. In 2 of 3 years, cultivation increased yield as compared to non-cultivated, weed-free carrots; cultivation reduced yield during the third year. In addition, undesirable carrot branching was greater where the crop was cultivated in 2 of 3 years when compared to the non-cultivated check. These results suggest that cultivation of small-seeded crops such as carrot can be difficult and variable.

In-row mechanical weed control


Summary: Finger and torsion in-row weeder were compared with a broadcast flex-tine harrow in onion and sugar beet. Early-season cultivation caused severe crop damage. While weed control was greater in onions with the flex-tine harrow, yield reductions were also greater, suggesting a lack of selectivity. In-row weeding reduced labor requirements by 50%.

Figure 3. Differences in weed growth and snap bean yield due to use of different cultivation tools. Adapted from Colquhoun et al.
Integrated weed management

The most successful weed control programs combine multiple management strategies. There are several benefits to an integrated program:

- The risk of complete weed control failure drops when using multiple strategies, since the chance that all strategies would simultaneously fail is minimal.

- Multiple strategies minimize the chance of selecting for weeds that tolerate or resist a single control strategy. For example, perennial grass weeds such as quackgrass are often not controlled by flex-tine cultivation, but may be suppressed by a competitive cover crop and timely mowing.

- Integrated weed management programs provide season-long weed control, minimizing competition between the crop and weeds and limiting production of weed seeds. For example, beginning the season using the stale seedbed system, followed by timely in-season control strategies such as cultivation or flame weeding can delay weed emergence and development to the point where no mature weed seed is present by crop harvest. Timely mowing after harvest will then prevent weed seed production, and winter cover crops will suppress future weeds.

And finally, be sure to consider the crop rotation when planning integrated weed management programs. By controlling weeds well during the part of the crop rotation that allows the most weed management strategies and greatest weed suppression by the crop, you’ll reduce weed pressure during more difficult crops in the rotation. A little bit of planning can make a world of difference when growing less-competitive crops in the rotation!