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Sustainable Weed Management for Small and Medium-Scale Farms

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Managing croplands according to nature's principles will reduce weed problems on horticultural crops, or row crops, in small and medium-sized operations. Creativity is key to devising sustainable cropping systems that prevent weed problems. This publication discusses several strategies, both proactive and reactive, as alternatives to conventional tillage systems. Options include mulching, competition, crop rotations, and low-toxicity control alternatives. A resource list provides sources of further information.

Contents

A thistle about to bloom is bad news. Photo: NCAT

Acknowledgments
This publication draws material from the ATTRA publications *Principles of Sustainable Weed Management for Croplands* and *Overview of Cover Crops and Green Manures* by Preston Sullivan, *Equipment and Tools for Small-Scale Intensive Crop Production* by Andy Pressman, and *Weed Management in Organic Small Grains* by Susan Tallman.

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Introduction

Why are weeds a problem? Weeds compete with crops for light, water, and nutrients, and they can affect a farm's economic bottom line. Weeds can reduce crop yields through competition with cash crops, harbor pests and disease, and even be problematic in the harvesting process. Consequently, a great deal of energy, effort, and money is devoted to controlling weeds. Minimizing weed growth both in the short term and the long term should be a goal when designing a cropping system. Careful planning to limit weeds' competition with cash crops, and to reduce the amount of time, fuel, and other resources spent on controlling weeds, can be vital to a farm's economic viability.

The "weed control" paradigm is reactive: it addresses weed problems by using various tools and technologies. "How am I going to get rid of this velvetleaf?" and "How do I control foxtail?" are reactive statements. The conventional tools to "get rid of" or "control" weeds—cultivation and herbicides—are reactive measures for solving the problem.

Farmers would generally agree that weeds are not in the field because of a deficiency of herbicides or cultivation. Rather, weeds are the natural result of defying nature's preference for high species diversity and covered ground. Nature is trying to move the system in one direction, and the farmer in another. We create weed problems through conventional crop-production methods. After we create these problems, we spend huge sums of money and labor trying to "control" them.

The opposite of reactive thinking is proactive thinking, by which we seek what we want through effective design and planning. A proactive approach to weed management asks, "Why do I have weeds?" This publication will introduce you to some proactive principles of cropland management that can make weeds less of a problem. It also offers some reactive strategies to deal with the weeds that remain bothersome.

Related ATTRA Publications
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Principles of Sustainable Weed Management for Croplands

Weed Management in Organic Small Grains

Overview of Cover Crops and Green Manures

Flame Weeding for Vegetable Crops

Conservation Tillage

Equipment and Tools for Small-Scale Intensive Crop Production

The Successful Weed

Weeds can be divided into two broad categories—annuals and perennials. Annual weeds are plants that produce a seed crop in one year, then die. They are well adapted to succeed in highly unstable and unpredictable environments brought about by frequent tillage, drought, or other disturbance. They put much of their energy into making seed for the next generation. This survival strategy serves plants in disturbed environments well, since their environment is likely to be disturbed again. The annual plant must make a crop of seed as soon as possible, before the next disturbance comes. Annual plants also produce more seed than do perennial plants. When we establish annual crop plants using tillage (i.e., disturbance), we also create an environment desirable for annual weeds.

Characteristics of a highly successful annual weed include:

- sprouting requirements that can be met in many environments
- long-lived seed
- variable seed-dormancy habits
- rapid vegetative growth
- high seed production
- some seed produced even in harsh conditions
- effective seed-dispersal habits

Perennial weeds come back every year, and prosper in less-disturbed and more stable environments. They are more common under no-till cropping systems. Their objective is to put some energy into preserving the parent plant while producing a modest amount of seed for future generations. After a field is converted from conventional tillage to no-till, the weed population generally shifts from annual to perennial weeds. Perennial weeds share many of the characteristics of annual weeds: competitiveness, seed dormancy, and long-lived seed. In addition to these characteristics, many perennial weeds possess regenerative parts such as stolons, bulbs, tubers, and rhizomes. These parts allow the parent plant to regenerate if damaged and to produce new plants from itself without seed. Additionally, the regenerative parts serve as food-storage units that also enhance survival. These stored-food reserves allow for the rapid re-growth that perennial weeds are known for.

The Root Cause of Weeds

When a piece of land is left fallow, it is soon covered over by annual weeds. If the field is left undisturbed for a second year, briars and brush may start to grow. As the fallow period continues, the weed community shifts increasingly toward perennial vegetation. By the fifth year, the field will host large numbers of young trees in a forest region, or perennial grasses in a prairie region. This natural progression of different plant and animal species over time is a cycle known as succession. This weed invasion, in all its stages, can be viewed as nature's means of restoring stability by protecting bare soils and increasing biodiversity.

Weeds are evidence of nature struggling to bring about ecological succession. When we clear native vegetation and establish annual crops, we are holding back natural plant succession, at great cost in weed control. To better understand this process, think of succession as a coil spring. Managing cropland as an annual monoculture compresses the spring—leaving it straining to release its energy as a groundcover of weeds. In contrast, a biodiverse perennial grassland or forest is like the coil spring in its uncompressed condition—a state of relative stability with little energy for drastic change (Figure 1). Generally speaking, biodiversity leads to more stability for the ecosystem as a whole.

Modern crop agriculture typically consists of a single crop-plant type on otherwise bare ground—an ideal environment for annual weeds to prosper in the first stage of succession. On large acreages, this unstable agro-ecosystem is usually managed with big investments in cultivation, mowing, herbicides, and fertilizers. On a small farm, however, producers may find that a more effective strategy is to utilize multiple techniques, such as weed prevention through mulching and cover cropping combined with cultivation and crop rotation.

A high diversity of plants and animals increases the stability of the whole agro-ecosystem. For example, an insect outbreak could wipe out a pure stand of a crop because the insects can easily move from one plant to the next and breed rapidly. The insects' favorite food is all around, and in a monocrop there are few predators or parasites to hamper them. The same insect invasion occurring in a mixture of many plant types would be less severe on any one type of plant because the insects would have a harder time finding their preferred food. The insects would be undernourished, have more difficulty finding a mate, and have lower reproductive rates. The end result is that the impact of an insect outbreak is much less severe on the whole ecosystem where high biodiversity prevails. Stability through biodiversity is one of nature's fundamental rules.

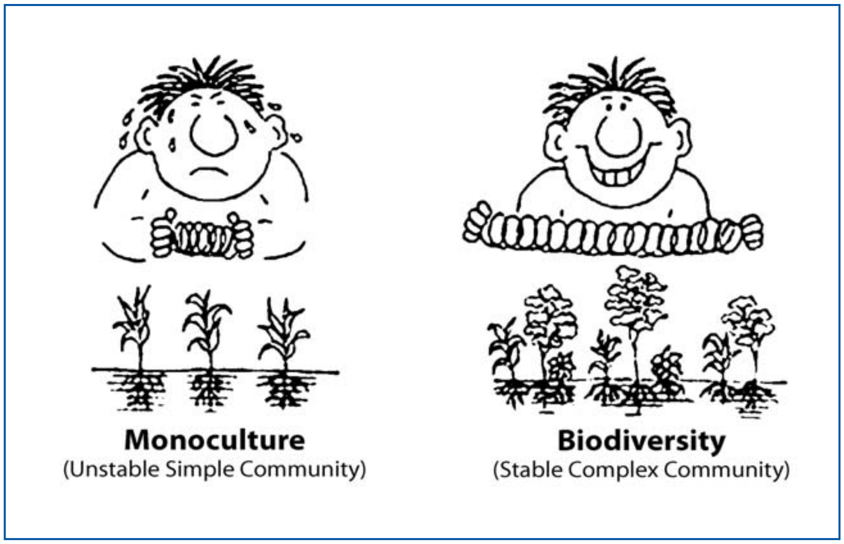

Figure 1. Monoculture vs. Biodiversity. Source: Savory, 1988

Understanding Weed Seed Banks and Germination

Weed seeds have a host of characteristics that assure their survival. They are adapted to many types of disturbance and harsh climatic conditions. Weeds have several seed-dispersal mechanisms (often aided by humans), assuring wide distribution. Their seeds last a long time in the soil without rotting. Additionally, seeds can go dormant until favorable conditions come around again.

Weed-seed distribution and density in agricultural soils are influenced by cropping history and the management of adjacent landscapes, and may be highly variable. A study of western Nebraska cropland found 140 seeds per pound of surface soil, equivalent to 200 million seeds per acre (Wilson, 1988). Redroot pigweed and common lambsquarter accounted for 86%. Growing without competition from other plants, a single redroot pigweed plant can produce more than 100,000 seeds, while a common lambsquarter plant can produce more than 70,000 seeds (Stevens, 1954).

New weed species can enter fields by many routes. Equipment moved from one field to the next—especially harvest equipment—spreads weed seeds, as does hay brought from one farm to another. Crop seed is often contaminated with weed seed, and livestock transport weed seeds from one farm to another in their digestive tracts and in their hair. Practical actions that can be taken to prevent the introduction and spread of weeds include using clean seed (check the seed tag for weed-seed levels), cleaning equipment before moving from one field to the next, and composting manures that contain weed seeds before applying them to the field.

Survival and germination of weed seeds in the soil depend on the weed species, depth of seed burial, soil type, and tillage. Seeds at or near the soil surface can easily be eaten by insects, rodents, or birds. Also, they may rot or germinate. Buried seeds are more protected from seed-eating animals and buffered from extremes of temperature and moisture. On average, about 4% of broadleaf and 9% of grass weed seeds present in the soil germinate in a given year (Lehnert, 1996).

After a seed is shed from the parent plant, it can remain dormant or germinate. There are several different types of dormancy. Seeds with hard seed coats possess "innate" dormancy. Several weed species, including pigweed, have seed coats that require mechanical or chemical injury and high-temperature drying to break dormancy. Another type of innate dormancy can best be described as after-ripening, meaning the seed requires further development after it falls off the plant before it will germinate. Several grass and mustard family weeds require after-ripening (Schlesselman et al., 1989). "Induced" dormancy results when seeds are exposed to unfavorable conditions, such as high temperatures, after being shed from the parent plant. "Enforced" dormancy occurs when conditions favorable to weed germination are absent. The seeds remain dormant until favorable conditions return. Altogether, multiple types of dormancy ensure that some weed seeds will germinate and some will remain dormant for later seasons.

Some weed species are dependent on light for germination; some germinate in either light or darkness; others germinate only in the dark. Thus, there are no hard-and-fast rules for managing an overall weed population according to light sensitivity.

Manure application may stimulate weed germination and growth. Studies have shown that poultry manure does not contain viable weed seeds, yet weed levels often increase rapidly in pastures following poultry manure application. Since chickens and turkeys have a gizzard capable of grinding seeds, weed seeds are not likely to pass through their digestive systems intact. The weed germination is probably caused by effects of ammonia on the weed-seed bank already present in the soil. The effect varies depending on the source of the manure and the weed species present. Manure from hoofed livestock (e.g., sheep, cattle, and horses), on the other hand, may indeed contain viable weed seed that has passed through animals' digestive systems. Composted manure contains far fewer viable weed seeds than does raw manure because the heat generated during the composting process kills seeds.

Fertilization practices can also affect weed germination. Where fertilizer is broadcast, the entire weed community is fertilized along with the crop. Where fertilizer is banded in the row, it is primarily the crop that gets fertilized.

Proactive Weed-Management Strategies

Thus far, we've seen that weeds are a symptom of land management that defies nature's design. Stirring the soil with tillage creates conditions favorable for weed germination and survival. Monocultures of annual crops hold natural plant succession back and minimize biodiversity, inviting weed populations to thrive. When we try to maintain bare ground, weeds grow to cover the soil and increase biodiversity. If we take a proactive approach to the whole agricultural system, rather than just looking at the parts, we can use the principles of nature to our advantage instead of fighting them.

Mulching

While mulching has many benefits, the basic idea behind mulching for weed control is to create a physical barrier between the weed and the sunlight and air, thus preventing seeds from sprouting and plants from growing. With enough mulch, weed numbers can be greatly reduced.

Nebraska scientists applied wheat straw in early spring to a field where wheat had been harvested the previous August. At high straw rates, weed levels were reduced by more than two-thirds (see Figure 2). Wheat, like rye, is also known to possess allelopathic qualities, which may have contributed to the weed suppression.

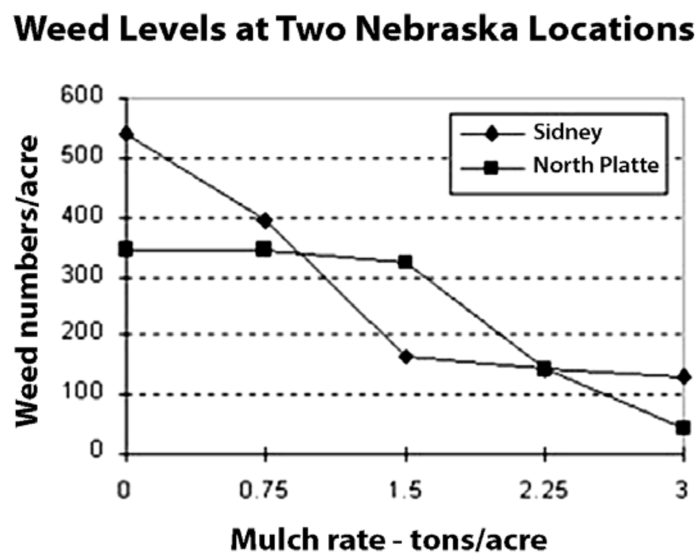

Figure 2. Effect of wheat straw mulch on weed levels at two locations in Nebraska. Source: Crutchfield et al., 1985

Mulches can be organic, such as straw, grass clippings, or dead leaves, or synthetic, like plastic film. Organic mulch is generally cheaper and easier to acquire than plastic mulch—you might even produce it yourself— and its slow decomposition will also add organic matter to your soil. Additionally, it has the ability to cool soil temperature slightly, potentially slowing down weed growth. However, because materials like straw and grass clippings are applied in aggregate, not in a solid sheet, there can still be space for persistent weeds to poke through. When applying organic mulches, verify that the material has not been sprayed with herbicides, which can damage and stunt the growth of your crops.

Plastic mulches are used with heat-loving plants and promote an earlier harvest by raising the soil temperature. Plastic mulches come in a variety of colors that affect the soil temperature differently. Although black plastic mulch doesn't provide much heat to the soil, it effectively suppresses weeds. Synthetic mulches create a solid barrier that weeds cannot penetrate, and effectively smother all weed growth below them, but they are more costly to purchase and install than organic mulches and are more resource-intensive to produce. Plastic mulch also blocks all water and air movement between the soil and the surface, and thus is best suited to use with a drip irrigation system. Though some plastic mulches are made to be biodegradable, organic certification requires annual disposal of plastic mulch.

Somewhere between organic and plastic mulches lies cardboard mulch—biodegradable, but still providing a physically impenetrable weed barrier. Cardboard mulch breaks down within one to two years. It is subject to premature degradation along its edges. Once the soil or rocks holding it down are no longer holding an attached part of the cardboard, this mulch can be caught by the wind and blown out of place. As with plastic, air has trouble penetrating cardboard mulch, and conditions beneath the mulch can become anaerobic. If the cardboard dries out, it can also become hydrophobic, meaning water won't be able to penetrate easily, and thus drip irrigation will be necessary.

A thick layer of straw mulch serves as a barrier to weeds in this crop of young garlic. Photo: Zoe Carlberg, NCAT

Crop Rotation

Crop rotations limit the buildup of weed populations and prevent major weed-species shifts. Weeds tend to prosper in crops that have requirements similar to their own. Fields of annual crops favor short-lived annual weeds, whereas maintaining land in perennial crops favors perennial weed species. In a crop rotation, the timing of cultivation, mowing, fertilization, herbicide application, and harvesting changes from year to year. Rotation thus changes the growing conditions from year to year—a situation to which few weed species easily adapt. Rotations that include clean-cultivated annual crops, tightly spaced grain crops, and mowed or grazed perennial sod crops create an unstable environment for weeds. Additional weed control may be obtained by including short-season, weed-smothering cover crops such as sorghum-sudan or buckwheat. Crop rotation has long been recognized for its ability to prevent weeds from developing to serious levels.

Incorporating crops with allelopathic effects into the rotation adds another element of control. Such crops include sunflowers, sorghum, and rapeseed. Allelopathic plants are those that inhibit or slow the growth of other nearby plants by releasing natural toxins, or "allelochemicals." Weed control ability varies among varieties and management practices. Sweet potatoes have been shown to inhibit the growth of yellow nutsedge, velvetleaf, and pigweed. Field trials showed a 90% reduction of yellow nutsedge over two years following sweet potatoes (Anon, 1993).

Competition

There are many ways to use cropping strategies to out-compete weeds.

Cover crops

Weeds flourish on bare soil. Cover crops take up space and light, thereby shading the soil and reducing the opportunity for weeds to establish themselves. Living mulches suppress weeds during

A densely planted cover-crop mix leaves little room for weeds to grow. Photo: Zoe Carlberg, NCAT

the growing season by competing with them for light, moisture, and nutrients. The soil-loosening effect of deep-rooting green manures also reduces weed populations that thrive in compacted soils.

The primary purpose of a non-legume green manure—such as rye, millet, or sudangrass—is to provide weed control, add organic matter, and improve soil tilth. These cover crops do not produce nitrogen. Thus, whenever possible, annual grain or vegetable crops should follow a legume green manure to derive the benefit of farm-produced nitrogen.

Short-duration plantings of buckwheat and sorghum-sudangrass smother weeds by growing faster and out-competing them. In northern states, oats are commonly planted as a "nurse crop" for alfalfa, clover, and legume-grass mixtures—the oats simply take the place of weeds that would otherwise grow between the young alfalfa plants.

Use of allelopathic cover crops and living mulches has become an important method of weed control in sustainable agriculture. Cover crop plants that exhibit allelopathy include the small grains, like rye, and summer annual forages related to sorghum and sudangrass. The mulch that results from mowing or chemically killing allelopathic cover crops can provide significant weed control in no-till cropping systems. Rye is one of the most useful allelopathic cover crops because it is winter-hardy and can be grown almost anywhere. Rye residue contains generous amounts of allelopathic chemicals. When left undisturbed on the soil surface, these chemicals leach out and prevent germination of small-seeded weeds. Weed suppression is effective for about 30 to 60 days (Daar, 1986). If the rye is tilled into the soil, the effect is lost.

A weed scientist in Michigan (Putnam et al., 1983) observed that some large-seeded food crops planted into rye mulch had high tolerance to the allelopathic effects, while smaller-seeded crops had less tolerance. In the study, corn, cucumber, pea, and snapbean no-till planted under rye mulch germinated and grew as well as or better than the same crops planted no-till without mulch. Smaller-seeded crops, including cabbage and lettuce, showed much less germination, growth, and yield. In this study, weeds that were reduced by rye mulch included ragweed (by 43%), pigweed (95%), and common purslane (100%).

Rapeseed, a type of mustard, has been used to control weeds in potatoes and corn under experimental conditions. All members of the mustard family (Brassicaceae) contain mustard oils that inhibit plant growth and seed germination (Boydston and Hang, 1995). The concentration of allelopathic mustard oils varies with species and variety of mustard.

In general, typical levels of cover-crop residues, when left on the soil surface, can be expected to reduce weed emergence by 75 to 90% (University of Connecticut, no date). As these residues decompose, the weed suppression effect will decline also. Residues that are more layered and more compressed will be more suppressive

A roller-crimper mounted to a tractor. Roller-crimpers simultaneously kill the cover crop and create a thick layer of mulch into which seeds or transplants can be planted. Photo: Andy Pressman, NCAT

(University of Connecticut, no date). Small-seeded weeds that have light requirements for sprouting are most sensitive to cover-crop residue. Larger-seeded annual and perennial weeds are least sensitive to residue. Effective management strategies include growing cover crops that produce high amounts of residue, growing slower-decomposing cover crops, packing the mulch down with implements that compress it, and using methods other than cover crops to control large-seeded annual and perennial weeds.

Transplanting and Plant Selection

By transplanting young plants instead of direct-seeding, or by planting fast-growing or aggressive crops in weed-prone areas, you give the crops a head start over the weeds. They then shade the weeds and establish first claim to sunlight, water, and nutrients.

Dense Plantings and Intercropping

Plant your crops close together, and/or incorporate intercropping to take advantage of vertical and horizontal space. This helps both to crowd out weeds and to get more out of your beds.

Efficient Watering and Fertilizing

Indiscriminate watering and fertilizing (such as with sprinklers) wastes resources and encourages weeds to grow (or at least the weeds that benefit from added water and fertility, which isn't all of them). Reserving water and fertilizer for crop plants only gives these a competitive advantage.

Reducing the Seed Bank

Mowing

Frequent mowing of farm margins and any areas of the farm not in cultivation can prevent weeds from producing seeds. This helps prevent the addition of new seeds blowing or being carried in to the seed bank. In combination with other practices, mowing can be effective in significantly reducing the seed bank over time.

Soil Solarization

Soil solarization heats the top layer of soil to temperatures high enough to kill many weed seeds, as well as soil pathogens. In this process, moist soil is covered by clear-plastic film for a period of several weeks during summer. A two- to four-week

If not mown or removed soon, the seeds from these margin weeds could make their way back to the farm. Photo: Zoe Carlberg, NCAT

period during which the soil temperature is at 99°F is effective in killing the seeds of many types of annual weeds. However, heating the soil to this degree affects many other soil factors, including microbial life and nutrient availability, so further research should be done before implementing this process and planting into solarized soils (Pokharel, 2011).

Stale Seedbed Preparation

In this management strategy, after seedbed tillage is completed, weed seeds, mostly in the upper two inches of the soil, are allowed to sprout. Assuming adequate moisture and a minimum soil temperature of 50ºF (to a depth of two inches), this should occur within two weeks. A fine to slightly compacted seedbed will germinate a much larger number of weeds. The weeds are then "seared" with a flamer, or burned down with a broad-spectrum herbicide, preferably when the population is between the first and fifth true-leaf stages, a time when they are most susceptible. The crop should then be seeded as soon as possible, and with minimal soil disturbance to avoid bringing new seed to the surface. For the same reason, subsequent cultivations should be shallow (less than two inches deep) (Pieri, no date).

Reactive Weed-Management Strategies

When selecting a tool for weed management, it helps to understand the weed's growth stages and to attack its weakest growth stage (the seedling

Table 1. Listing of practices and their effect on biodiversity.	
Increase Biodiversity	**Decrease Biodiversity**
Intercropping	Monocropping
Rotations	Tillage
Cover crops	Herbicides
Strip cropping	Cultivation

stage). Alternatively, management techniques that discourage weed-seed germination could be implemented. A farmer should select a means of control that requires the least amount of resources.

The various practices available for weed management fall into two categories: those that enhance biodiversity in the field and those that reduce it (Table 1). This is not to imply a "good vs. bad" distinction. Rather, it is meant to describe the effect of the tool on this important characteristic of the crop/weed interaction. In general, as plant diversity increases, weeds become less of a problem.

Hand Pulling

One of the easiest and most straightforward methods of weed removal is hand pulling. It is an effective strategy for selectively removing weeds that are scattered around an area or for eradicating a patch of an invasive weed before it can become established or produce seed. When weeds have already begun producing seeds, careful hand-pulling can be better than other mechanical methods at preventing the seeds from spreading. However, it is also the most labor-intensive method of weed control and, as such, is generally only worthwhile on a very small scale.

A tractor-mounted flame weeder in operation at Holcomb Farm in Connecticut. Smaller-scale flame weeders are also available, from hand-pushed weeders that span beds all the way down to backpack-mounted weeders. Photo: Courtesy of Holcomb Farm CSA

Flame Weeding

Pre-planting, pre-emergent, and post-emergent flame weeding have been successful in a number of crops. The pre-plant application has commonly been referred to as the "stale seedbed technique," described above.

Pre-emergent flaming may be done after seeding, and, in some crops, post-emergent flaming may be done, as well. Flaming is often used as a band treatment for the crop row, and is usually combined with inter-row cultivation. Early flaming may be done in corn when it is one-and-a-half to two inches high. The growing tip is beneath the soil surface at this stage, and the crop readily recovers from the leaf damage. Subsequent post-emergent flamings may be done when corn reaches six to 10 inches in height, and later at lay-by. No flaming should be done when corn is at approximately four inches high, as it is most vulnerable then. On a flamer, the burners are offset to reduce turbulence and to avoid concentrating too much heat on the corn. Water shields are available on some flame-weeder models. Uniform seedbed preparation and uniform tractor speed are important elements in flaming. Hot and dry weather appears to increase the efficacy of flaming (Cramer, 1990).

Searing the plant is much more successful than charring. Excessive burning of the weeds often stimulates the roots and encourages regrowth, in addition to using more fuel. Flaming has generally proved most successful on young broadleaf weeds. It is reportedly less successful on grasses, as the seedlings develop a protective sheath around the growing tip when they are about one inch tall (Drlik, 1994). Some concerns with the use of fire include possible crop damage, potential dangers in fuel handling, and the cost of fuel. For more information on flame weeding, see the ATTRA publication *Flame Weeding for Vegetable Crops.*

Livestock

Weeder geese have been used successfully both historically and in more recent times. They are particularly useful on grass weeds (and some others, too) in a variety of crops. Chinese or African geese are favorite varieties for weeding purposes. Young geese are usually placed in the fields at six to eight weeks of age. They work well at removing weeds between plants in rows that cannot be reached by cultivators or hoes. If there are no trees in the field, temporary shade will be needed. Supplemental feed and water must be provided as well. Water and feed containers can be moved to concentrate the geese in a certain area. A 24- to 30-inch fence is adequate to contain geese. Marauding dogs and coyotes can be a problem and should be prevented with electric fencing or guard animals. At the end of the season, bring geese in for fattening on grain. Carrying geese over to the next season is not recommended because older geese are less active in hot weather than younger birds. Additionally, the cost of over-wintering them outweighs their worth the next season. Geese have been used on the following crops: cotton, strawberries, nursery trees, corn (after lay-by), fruit orchards, tobacco, potatoes, onions, sugar beets, brambles, other small fruits, and ornamentals.

Additionally, chickens can be effective at consuming weed seeds near the surface, if pastured in a field prior to planting. Also, managed grazing by ruminant livestock can help reduce weed populations in fields during the off-season and can help reduce production of weed seeds elsewhere on a small farm, thus reducing weed-seed levels much the way that mowing can.

Be aware when using any livestock (including chickens and geese) for weed control in crop fields, however, that there are important food-safety considerations. Livestock are essentially applying raw manure to crop fields, so their use should be timed and managed to prevent food-crop contamination, in accordance with state and federal standards. As of this writing, there has not been a final ruling on raw-manure application standards under the Food Safety Modernization Act (FSMA), but the standards will likely restrict raw-manure applications to more than 120 days prior to harvest for any food product that comes in contact with the manure. Check with local health officials before using livestock to manage weeds in your production areas to learn what the current regulations are.

Cultivation and Tillage

Tillage and cultivation are traditional means of weed management in agriculture. Both expose bare ground, which is an invitation for weeds to grow. Bare ground also encourages soil erosion, speeds organic-matter decomposition, disturbs soil biology, increases water runoff, decreases water infiltration, damages soil structure, and costs money to maintain (for fuel and machinery or for hand labor), so limiting tillage, when possible, has its benefits.

There are many types of tillage and cultivation equipment that serve a variety of functions on a variety of scales. The University of Vermont Extension has put together a great series of video clips titled "Vegetable Farmers and their Weed Control Machines," featuring nine New England farmers demonstrating their cultivation equipment, available online at www.extension.org/pages/18436/video:-vegetable-farmers-and-their-weed-control-machines or for purchase by calling 802-656-5459. The following photos illustrate some of this equipment:

Hoeing works best on very small scales to remove young weed seedlings. There are several types of hand-held hoes. From left to right: a collinear hoe, a swan neck hoe, a stirrup hoe, a "regular" hoe, and an eye-hoe. Photo: Andy Pressman, NCAT

Wheeled hoes add an element of efficiency to the traditional hoe; smaller wheels are more efficient and easier to manage than larger ones. Here is a wheel hoe with a four-tine cultivator attachment. Photo: Andy Pressman, NCAT

A basket weeder belly-mounted to an Allis Chalmers G at Pennypack Farm and Education Center in Horsham, Pennsylvania. The Allis Chalmers G was designed specifically for vegetable crop production, but is no longer manufactured. Photo: Andy Pressman, NCAT

Finger weeders at work in celery transplants. Photo: Richard Smith, courtesy of UC Cooperative Extension

A close-up of sweeps. Photo: Andy Pressman, NCAT

S-tine cultivator with sweeps, and a wheel that acts as a harrow on the back. Photo: Andy Pressman, NCAT

Some specific tillage guidelines and techniques for weed management are introduced below.

Pre-Plant Tillage

Where weeds such as quackgrass or johnsongrass exist, spring-tooth harrows and similar tools can be effective in catching and pulling the rhizomes to the soil surface, where they desiccate and die. Discing, by contrast, tends to cut and distribute rhizomes and may make the stand even more dense. For limited pre-plant tillage on a smaller scale, a broadfork can be effective in loosening the soil enough for hand-removal of weeds, and following this with a rake creates a smooth seedbed without exposing too many weed seeds to light.

Blind Cultivation

Blind cultivation is a pre-emergent and early post-emergent tillage operation for weed control, in which cultivation instruments are run across the entire field, including directly over the rows. The technique works on large-seeded crops like sweet corn, beans, and squash, as well as on transplants, which all can survive with minimal damage, while small-seeded weeds are easily uprooted and killed. Finger weeders and tine weeders are two popular tools for this, ideal for small acreages planted to high-value crops. These can only be used when crops are young, but the best stage of growth in which to use them depends on the crop. Post-emergent blind cultivation should be done in the hottest part of the day, when crop plants are limber, to avoid excessive damage. When using implements that cultivate exclusively within rows, additional weed-management strategies will need to be employed between rows. Seeding rates should be increased 5 to 10% to compensate for losses in blind cultivation (Anon, 1991; Cooperative Extension Service, 1997; Smith, 2013).

Row-Crop Cultivation

Cultivation is best kept as shallow as possible to reduce the number of weed seeds brought to the soil surface. Where perennial rhizome weeds are a problem, the shovels farthest from the crop row may be set deeper on the first cultivation to bring rhizomes to the surface. Tines are more effective than duck feet sweeps for this purpose. Later cultivations should have all shovels set shallow to avoid excessive pruning of crop roots. Earliest cultivation should avoid throwing soil toward the crop row, as this places new weed seed into the crop row where it may germinate before the crop canopy can shade it out. Use row shields as appropriate. As the crop canopy develops, soil should be thrown into the crop row to cover emerging weeds.

Inter-Row Cultivation

Inter-row cultivation is best done as soon as possible after precipitation, once the soil is dry enough to work. This avoids compaction, breaks surface crusting, and catches weeds as they are germinating—their most vulnerable stage.

For additional information on appropriate tools for tillage and cultivation on small farms, both mechanized and non-mechanized, see pages 9-11 of ATTRA's publication *Equipment & Tools for Small-Scale Intensive Crop Production.*

Generally speaking, tillage systems tend to discourage most biennial and perennial weed species, leaving annual weeds as the primary problem. Exceptions to this are several weeds with especially resilient underground rhizome structures such as johnsongrass, field bindweed, and quackgrass. Plowing of fields to bring up the rhizomes and roots has been used to control bindweed and quackgrass.

An interesting application of timing to weed control is night tillage. Researchers have found that germination of some weed species is apparently triggered by exposure to light. Tillage done in darkness exposes far fewer seeds to light and reduces weed pressure. Small-seeded broadleaf weeds (lambsquarters, ragweed, pigweed, smartweed, mustard, and black nightshade) appear to be most readily affected (Becker, 1996).

Herbicides

For the purposes of this publication, we will cover least-toxic and organic herbicides. If you are certified organic, always check with your certifying agency before using an herbicide, as variations on certain formulations may or may not be allowed for use on organic farms.

Least-Toxic Herbicides

Corn gluten meal is a byproduct of the process of milling corn and has been used successfully on lawns and high-value crops as a pre-emergent herbicide that inhibits growth and root development. It is non-selective and must be applied carefully to ensure crop safety. It must be applied just prior to weed-seed germination to be effective. A common rate is 40 pounds per 1,000 square feet, which suppresses many common grasses and herbaceous weeds. Corn gluten meal cannot be derived from genetically modified (GM) corn if being used in an organic operation (Dufour et al., 2013; Quarles, 1999).

Herbicidal soaps made from fatty acids are available from companies like Safer Brand and Mycogen. They are fast-acting, broad-spectrum herbicides, and results can often be seen within hours. Herbicidal soaps are used as a post-emergent, sprayed directly on the foliage, and are most effective on annual broadleaf weeds and grasses.

Vinegar is an ingredient in several organically approved herbicides on the market today, with acetic acid levels of 5 to 30% or more (household vinegar is about 5% acetic acid). Vinegar-based herbicides are effective as post-emergent herbicides sprayed onto the plant to burn off top growth—hence the concept "burndown." Burndown treatment is most effective on small annual weeds and is less effective on grasses than it is on broadleaf weeds.

Researchers in Maryland (Anon, 2002) tested 5 and 10% acidity vinegar for effectiveness in weed control. They found that older plants required a higher concentration of vinegar to kill them. At the higher concentration, they got an 85 to 100% kill rate. A 5% solution burned off the top growth with 100% success. Vinegar is corrosive to metal sprayer parts—the higher the acidity, the more corrosive. Plastic equipment is recommended for applying vinegar. It is also very important to wear hand and eye protection when applying, as acetic acid concentrations of greater than 10% can cause serious damage (Dufour et al., 2013).

Clove oil is another active ingredient in organic post-emergent, non-selective herbicides, and it can be just as effective as acetic acid at controlling broadleaf weeds. Additionally, it can be applied at lower rates than acetic acid while retaining its efficacy (Dufour et al., 2013).

USDA Agricultural Research Service is researching a method called Propelled Abrasive Grit Management, "a tractor-mounted system that uses compressed air to shred small annual weeds like common lambsquarters with high-speed particles of grit made from dried corn cobs" (Suszkiw 2014). The method shows promise for organic weed control, but there are still questions that remain—for example, whether grit made from cobs of genetically modified corn can be used in certified organic systems, and how well the spraying controls grass weeds.

Edible Weeds

Many of our most common weeds are actually edible, and you may find it an attractive option to harvest some of these and sell them as specialty crops or elements of salad mixes to get a little more out of your weeding efforts.

As with leafy crops grown for greens, smaller, more tender weed leaves are better for fresh eating, as in salads, and larger, tougher leaves are better cooked, to soften them and remove bitterness.

Caution with edible weeds: do not sell or eat any plants that you have not positively identified with the help of a guidebook, professional, or Extension agent. Take the same care with these plants regarding sanitation as you would with your crop plants.

Conclusion

Weed management on small and medium-scale farms will often require a combination of preventive and reactive strategies. The more preventative work a farmer does, the less reactive he will have to be in the long run. Sustainable farmers must control weeds before they get established. A strong effort in controlling perennial weeds and preventing seed production in annual weeds will save you much work in years to come. The strategies and examples described in this publication should help set you on a path to a farm that has a manageable weed population. See the Further Resources section for more detailed information on the strategies described in this publication.

Table 2. Some common edible weeds

Plant	Leaves	Flowers	Seeds	Stalks	Notes
Chickweed	yes	yes		yes	Harvest tender plants not growing in full sun. High in vitamin C and B vitamins, copper, and iron.
Curled Dock	yes				Considered by some to be the best-tasting wild vegetable.
Dandelion	yes	yes			Young leaves can be used like salad greens or cooked
Lambsquarters	yes		yes		Similar to spinach, with protein, calcium, vitamins A, C, K
Pigweed/ Green Amaranth	yes				Best cooked to avoid upset stomach. Vitamin-rich.
Purslane	yes	yes	yes	yes	Omega-3s, vitamins A and C. Like a tangy, succulent spinach, good in salads, and can be substituted for okra as thickener.
Watercress	yes				Great in salads
Wood Sorrel	yes		yes (whole pods)		Crisp and tart, can be substituted for rhubarb or vinegar depending on recipe
Violet	yes	yes			High in vitamins A and C, calcium, and iron. Young leaves more tender. Best eaten in smaller quantities due to laxative qualities.

Sources: Rodale, no date; Ditzel, 1976; Duchon, 1992; Doiron, 2008

Case Study: A Whole-Farm Approach to Managing Weeds in Onions: Anne and Eric Nordell's Beech Grove Farm, Pennsylvania

By Tammy Howard, NCAT Agriculture Specialist

Managing weeds in organic farming is a continuous and evolving challenge. Onions are a particular problem because the crop may be in the field from very early spring through early fall. Onions also have relatively little canopy protection and are shallow-rooted. Anne and Eric Nordell have developed a truly innovative strategy of managing weeds using cover crops and rotations.

Beech Grove Farm is located on 90 acres in north-central Pennsylvania. The Nordells operate their diversified vegetable farm using their own hands and four draft horses. They grow the bulk of their cash crops on a well-drained 6-acre field that is divided into a dozen half-acre lots.

At any one time in the growing season, half the cropping area is in cash crops and the other half is fallow. A field of spring-planted crops next has a year of fallow, then summer-planted crops. On the fallow sections, they use two cover crops and a bare fallow to control weeds. With this rotation sequence, they build their soil and eliminate weeds.

An excellent illustration of this system is the Nordells' ground preparation for onion production. The fallow sequence begins a full year in advance of planting. In the fall, after the cash crop has been harvested from the plot where the onions will go, the Nordells seed winter-hardy rye. The following spring, when the rye begins growing in earnest, they mow it using a sickle bar.

Throughout the spring, this is done three times in alternating directions whenever the rye regrows to about two to two-and-a-half feet. Repeated clipping prevents the rye from going to seed and encourages tillering (the growth of additional side stalks). The result is a partially rotted rye that serves as sheet compost.

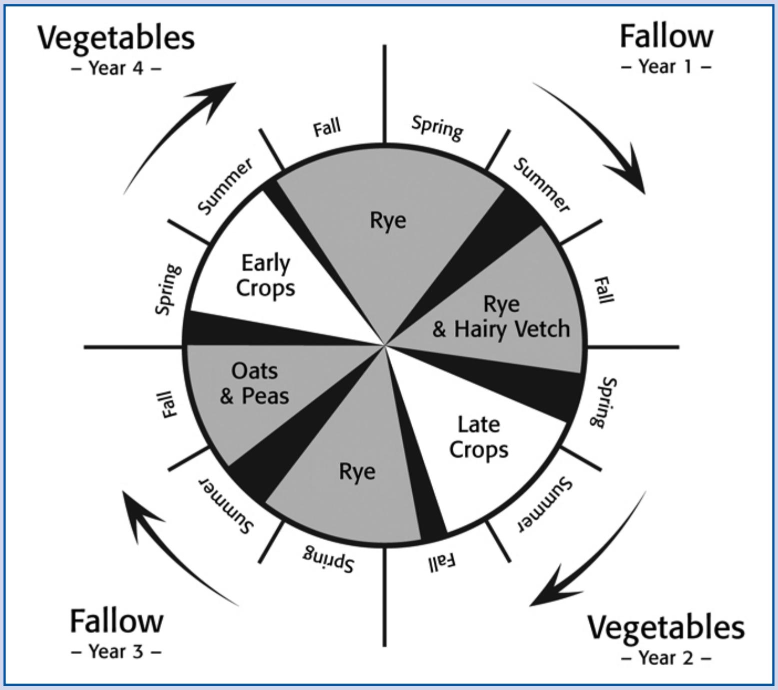

Figure 3. The Cover Crop Clock. Source: Anne and Eric Nordell

In late June, after the third mowing—when the rye has put on the bulk of its growth, but summer weeds have not yet had a chance to seed—they plow the field with narrow, deep furrows. This is done by removing the jointer and adjusting the plow to cut the furrow so that it almost slices the soil, laying the residue on its side. This method of plowing helps maintain soil structure, permits air and moisture circulation, and aids in decomposition. By deep plowing at this time, they target the perennial weeds at the weakest point in their life cycle. The technique breaks down the highly carbonaceous materials when the soil is biologically active, without robbing it of nitrogen.

At this point, cultivating with a springtooth harrow over a five- to six-week period brings perennial rhizomes to the surface to dry out and knocks down annual weeds at their peak growth. Then the Nordells apply well-composted manure that is virtually free of weed seed. This timing allows the manure to break down before the cash crops are planted and saves a step in the spring, while enhancing the root and top growth of the fall-planted cover crop.

In about mid-August, they plant spring annuals such as oats and peas because these crops put on a lot of top growth in the fall and then winter-kill, leaving an easily incorporated residue that allows timely planting of onions. In the spring, the Nordells shallowly till the soil to avoid bringing weed seeds to the surface. They plant their onions into this and plan on cultivating three times during the season—to keep moisture in the soil, rather than to control weeds.

More recent field experiments from the Nordells include a bare fallow tillage in the spring rather than summer to aggressively target cool-season weeds, interseeding a single row of cover crops into pathways to add additional nitrogen and organic matter, and no-till onions in fields where there is no cool-season weed pressure.

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Further Resources

Farm Hack
http://farmhack.net
An open-source community in which farmers and non-farmers develop and share do-it-yourself designs for improved farm implements online and at regular events.

Steel in the Field: A Farmer's Guide to Weed-Management Tools. 1997. Edited by Greg Bowman. Sustainable Agriculture Research and Education (SARE). www.sare.org/Learning-Center/Books/Steel-in-the-Field
This book is a farmer's guide to weed management tools using cultivation equipment.

Taming the Weeds While Saving Soil in Organic Crops. 2012. By M. Schonbeck. Presentation at South Carolina NRCS Employee Organic and Sustainable Agriculture Training. USDA Vegetable Lab, Charleston, SC. www.clemson.edu/sustainableag/Schonbeck_WeedsNRCS.pdf

Weed Management on Organic Farms. 2008. By D.M. Finney and N.G. Creamer. Center for Environmental Farming Systems, Goldsboro, NC. www.cefs.ncsu.edu/resources/organicproductionguide/weedmgmtjan808accessible.pdf

Weed Management on Organic Vegetable Farms Fact Sheet. No date. By Vern Grubinger. University of Vermont Extension, Burlington, VT. www.uvm.edu/vtvegandberry/factsheets/orgweedmgmt.html

What Really Happens When You Cut Chemicals. 1993. By C. Shirley and New Farm staff. Rodale Institute, Emmaus, PA.
This book contains a series of farmers' experiences with adopting new strategies for higher profits and lower input costs while enhancing the environment.

Notes

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