Weed Management on Organic Farms

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Special Topic: Cultivation Practices for Organic Crops

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Organic farmers struggling to develop effective and economical weed management practices are not alone. Farmers rank weeds as the number one barrier to organic production (Walz, 1999). And organic farmers cite weed management as their number one research priority.

In approaching weed management within an organic system, it is important to remember the central goal: to reduce weed competition and reproduction to a level that the farmer can accept. In many cases, this will not completely eliminate all weeds. Weed management should, however, reduce competition from current and future weeds by preventing the production of weed seeds and perennial *propagules* — the parts of a plant that can produce a new plant. Consistent weed management can reduce the costs of weed control and contribute to an economical crop production system.

This chapter describes weed control strategies for organic farms based on weed characteristics and an integrated cropping system approach:

Figure 1. Yellow starthistle *(Centaurea solstitialis*). Photo courtesy of USDA.

- **What is a weed?** Weedy plants share common characteristics that must be considered.

Chapter Contents

- **Preventing weeds.** Crop rotations, ,cover crops, stale seedbed preparation, soil solarization, proper sanitation, and composting can prevent weeds from emerging and spreading.
- **Increasing crop competitiveness.** Choosing the right cultivar, using transplants, seeding correctly, ensuring crop health, and applying mulches can give crops a competitive advantage.
- **Special topic: Cultivation practices for organic crops.** Using the right cultivation tools at critical times can contribute to a cropping system that limits both emerged and future weeds.
- **Additional tools for weed management.** Animals and approved herbicides can supplement cultural practices for weed control on organic farms.
- **What researchers are doing.** High-tech weed control, natural weed control, crop breeding, and cropping systems are key weed research areas.
- **Advantages of organic production.** Organic practices can create conditions that naturally limit weeds.

WHAT IS A WEED?

Despite its general acceptance, the term *weed* is not easily defined. What some farmers consider a weed, others will find innocuous or even charming. And what one may call a weed in a soybean crop, another may call a wildflower in a forest setting. Our perceptions of what a weed is will vary based on location, plant species, population size, and other factors. On a farm, weeds are those plants that negatively affect crop production. First and foremost, weeds compete with market crops for resources, such as light, nutrients, and water, and potentially reduce crop yields. Weeds also lead to increased production costs — the costs of controlling them *and* the insects and diseases they harbor. During harvest, weeds can interfere with machinery and further reduce crop quality through contamination. Despite the lack of a clear definition for every circumstance, plants that fall into the weed category have shared characteristics that earn them the "weedy" distinction.

Weed Characteristics

Weeds are highly competitive and successful organisms. Most weeds exhibit rapid seedling growth and an ability to reproduce when young, especially when they experience stress. Weeds mature quickly compared to most crop species, and many species thrive under a broad range of conditions. They can tolerate a wide range of adverse environmental conditions, such as drought stress and soil compaction. Weeds can scavenge and compete for resources, and they respond rapidly to favorable growing conditions. Furthermore, weeds have several characteristics that enhance reproductive capability:

- They reproduce via seeds, vegetative propagation, or both.
- They exploit different mechanisms for seed dispersal.
- They display *self-compatibility* (Zimdahl, 1999) — a single propagule is enough to start a sexually reproducing colony of plants. Self-compatible flowering plants can usually produce seed without visits from specialized pollinating insects.
- They produce a great number of seeds. Examples of species that produce a great number of seeds per plant include redroot pigweed *(Amaranthus retroflexus*, 117,000 seeds per plant), common purslane *(Portulaca olerace*a, 52,000), shepherd's purse *(Capsella bursa-pastoris*, 38,000), common lambsquarters *(Chenopodium album*, 28,000), and

yellow foxtail *(Setaria glauca*, 12,000) (Anderson, 1977).

Weed seeds also can be dispersed across time through extended dormancy. A classic longevity study involved 20 species of weed seeds that were buried in soil for more than 80 years (Darlington and Steinbauer, 1961). After 20 years, 11 of the buried species were still viable; after 40 years, 8 were still viable (including purslane, redroot pigweed, shepherd's purse, annual ragweed *(Ambrosia artemisiifolia),* and plantain *(Plantago major*); and after 80 years 3 species were still viable: curly dock *(Rumex crispus*), common evening primrose *(Oenothera biennis*), and moth mullein *(Verbascum blattaria*).

Together, these qualities make weeds tough adversaries, both for neighboring crops and the farmers who manage them.

Characteristics of Weeds

1. Display rapid seedling growth
2. Reproduce when young
3. Mature quickly
4. Tolerate a broad range of conditions
5. Have multiple reproductive strategies
6. Produce great numbers of seeds

PREVENTING WEEDS

Weed management within an organic farm relies on an integrated cropping-system approach. An organic farming system should be designed to create a balance between crop plants and weeds. Within such a system, farmers can take action to tip the balance in favor of crop plants whenever possible:

- **Culturalpractices**, including crop rotation, cover cropping, mulching, and cultivating, are important tools in a farming system that puts weeds at a disadvantage. These practices can also have secondary benefits for soil fertility, disease, and pest management.
- **Solarization and stale seedbed preparation** can keep weeds from emerging when the planting season begins.
- **Proper sanitation and composting** practices can stop the spread of weeds between fields and from outside the farm.

Crop Rotation

Organic farmers often use mixed cropping systems and long rotations to enhance soil fertility and economic diversity. Crop rotation also can be a cornerstone in a weed management plan. Through long-term variations of crop species and planting times, rotations create a changing environment and prevent the dominance of a particular weed species. Researchers have compared emerged weed densities in test crops grown in rotation versus continually grown test crops. For most of the crops studied, weed densities were lower when a crop was grown in rotation (Liebman and Dyck, 1993).

Knowledge of potential weed problems allows a farmer to select the rotation best suited to a particular field. When making a crop production plan, a farmer should design rotations for each field with weed management and potential weed problems in mind. For example,

- When a crop with a dense, closed canopy, such as potatoes, is grown prior to growing a crop that is less competitive with weeds, the dense crop reduces the development of weeds.
- Where late-germinating weeds are a concern, an early crop can be followed with tillage and a vigorous, competitive summer annual crop to suppress these weeds.

- If perennial weeds are a problem, a market crop can be rotated with a perennial crop that can be mowed repeatedly or grazed as a management strategy.
  (Bond and Grundy, 2001)

Further, rotations should be evaluated regularly to determine if problem weeds are surviving in the crop rotation scheme and to determine what adjustments need to be made for more effective management.

Cover Crops

Cover crops offer many benefits to an organic farming system, including protection against soil erosion, improvement of soil structure, soil fertility enhancement, and weed suppression. Cover crops can be used in a variety of ways to suppress weeds. Cover crops can suppress weeds, reduce weed populations in the subsequent crop, and reduce weed seed contributions to the soil seedbank:

- Annual or short-term perennial cover crops can be used in place of a fallow period to reduce soil erosion and maintain soil fertility while competing with weeds for resources, such as light, water, and nutrients.
- Cover crops that develop rapidly and form a dense canopy can keep sunlight from newly emerged weeds and outcompete them.
- Cover crops can also provide organic mulch or act as a living mulch to further suppress weed populations during the cropping season.

Cover Crop Residues as Mulch.

Annual cover crops may be killed or left to die naturally and used as mulch. By altering light, soil moisture, and soil temperature, mulches limit the germination and growth of weed seedlings. Dead cover crop residues serve as excellent mulch for no-till and reduced-tillage systems when left in a field. Cover crop residues may also be moved from one field to another. There is, however, a risk of transporting weeds into a field with mulch, including cover crop residues that are moved from one field to another. (Mulches applied after planting will be discussed later in this chapter.)

Consider the market crop. If cover crop residues will be used as mulch for no-till production, a farmer must consider the market crop that will follow the cover crop. For instance, if the market crop will be planted in early spring, it is best to choose a winter annual cover crop that will die back early, such as a mixture of oats and crimson clover. If the market crop will be planted in late spring or early summer, a mixture of longer-lived species, such as rye and hairy vetch, is preferred.

Effective cover crop kill. Another key to the successful use of cover crop residues is effective cover crop kill. Many no-till systems now used in the midwestern United States rely on chemical herbicides to kill cover crops. Organic farmers, however, must kill crops mechanically, which can be a considerable challenge.

Mechanical methods of killing cover crops that will be left on the soil surface include mowing, rolling, roll-chopping, and undercutting. The success of these methods depends, in part, on the species and growth stage of the cover crop. Optimal mechanical management promotes rapid desiccation and limits the regrowth of the cover crop species while leaving residues intact for mulch. Because mowing generates small pieces of residue that decompose quickly, this may not be the best method of mechanical kill. Rolling and undercutting cover crops can create a longer-lasting surface mulch that can provided extended weed suppression. Rolling also can be accomplished at higher speeds, with lower machinery maintenance costs and reduced fossil fuel consumption compared to mowing. Various methods have been tried for rolling and roll-chopping cover crops. Depending on conditions, an effective kill can result from breaking, cutting, crushing, or crimping stems. (See the recommended reading list: Creamer and Dabney, 2002; Creamer et al., 1995.)

Creamer et al. (1995) designed a modified undercutter to sever the cover crop roots and flatten the intact above-ground biomass on the surface of raised beds. This implement was designed to kill a cover crop with minimal soil disturbance, while leaving the maximum amount of cover crop residue on the soil surface and avoiding shredding the residue. The standards holding the undercutting blades are placed on the outside of the bed to prevent soil and residue disturbance. A rolling basket follows the blades to flatten and distribute the undercut cover crop and aid residue flow through the implement. The undercutter leaves a thicker, longer-lasting mulch on the soil surface than mowing and a noncompacted soil, which can facilitate transplanting of vegetable crops.

Cover Crops as Living Mulch. Certain cover crops also may be used as living mulches (this is often referred to as intercropping). Living mulches can be established before planting, or they can be seeded with or after the main crop has been planted. Seeding with or after the main crop is referred to as *interseeding* or *underseeding*. Living mulches may be annual or perennial cover crops, and they can be used with both annual and perennial cash crops.

Researchers have demonstrated that living mulches can effectively suppress weeds when grown with a cash crop. In 51 research trials in which main crops grown with a living mulch were compared to the main crop grown alone, weed biomass was lower in the living mulch system in 47 cases (Liebman and Dyck, 1993). In most instances, the researchers attributed weed suppression to competition from the intercrops, although it is possible that *allelopathy* — the suppressive effect of chemicals emitted by one species on another — also played a role in some systems (Vandermeer, 1989).

Considerations. The most significant challenge a farmer faces in using living mulch systems for crop production is competition between the living mulch and the market crop. Many examples of successful living mulch systems exist for vineyards and fruit orchards, but many attempts to use living mulches in annual cropping systems (Miura and Watanabe, 2002; Ateh and Doll, 1996; Mohler, 1995) or early in the establishment of perennial crops (Paine et al., 1995) have resulted in reduced growth and yields for the market crops.

Cover crops that are suitable for use as living mulches in intercropping systems should do the following (Enache and Ilnicki, 1990):

- Compete minimally with the market crop for resources, including light, water, and nutrients.
- Have characteristics that control weeds.
- Provide a regular and sufficient source of nitrogen.
- Have low maintenance costs.

The spatial arrangement, seeding rate, and planting time of living mulches should also create favorable conditions for the market crop. For most crops, it is best to confine the living mulch to between-row spaces.

During the growing season, a farmer may need to suppress a living mulch to reduce competition with the market crop. This can be done in an organic system by mowing, partial rototilling, and complete tillage, if necessary. In addition to above-ground competition for light, root competition between the living mulch and crop may reduce yield. (See Liedgens et al. in the "Recommended Reading" list.)

Table 1. A summary of research on effective living mulches by market crop

Market Crop	Cover Crop Species	Researcher
Broccoli	*Vicia villosa* (hairy vetch) *Trifolium incarnatum* (red clover) *Portulacca oleracea* (common purslane)	Foulds et al., 1991 Foulds et al., 1991 Ellis et al., 2000
Cabbage, spring	*Trifolium subterraneum* (subterranean clover)	Ilnicki and Enache, 1992
Corn, field	*Trifolium subterraneum* (subterranean clover)	Ilnicki and Enache, 1992
Corn, sweet	*Trifolium subterraneum* (subterranean clover) *Trifolium ambiguum* (kura clover) *Trifolium repens* (white clover, partial rototilling may be necessary to reduce competition)	Ilnicki and Enache, 1992 Zemenchik et al., 2000 Miura and Watanabe, 2002; Grubinger and Minotti, 1990
Snapbeans	*Trifolium subterraneum* (subterranean clover)	Ilnicki and Enache, 1992
Soybeans	*Trifolium subterraneum*	Ilnicki and Enache, 1992
Squash, summer	*Trifolium subterraneum*	Ilnicki and Enache, 1992
Tomatoes	*Trifolium subterraneum*	Ilnicki and Enache, 1992

Effective species. Clovers, particularly white clover (*Trifolium repens*), kura clover (*Trifolium ambiguum*), and subterranean clover (*Trifolium subterraneum*), are species with great potential for use as living mulches (Table x-1). These low-growing legumes are planted in late summer or fall and grow until winter dormancy. The clover crop flowers in late spring and then sets seed for the following fall. After flowering, vegetative growth dies, leaving a thick mulch. Annual cash crops can be planted into the clover while it is still growing in the spring. As the clover dies in late spring and early summer, it creates a weed suppressive mulch and is no longer a potential source of competition for the market crop.

For further information on living mulch systems, see the "Recommended Reading List" at the end of this chapter. The National Sustainable Agriculture Information Service (ATTRA) recommends the publication by Leary and De Frank (2000).

Allelopathic Cover Crops. In addition to physically suppressing weeds, cover crops can also suppress weeds through chemical means, a process known as *allelopathy*. Allelopathy is defined as "any direct or indirect harm induced in one plant through toxic chemicals released into the environment by another" (Rice, 1974). Research is underway to determine how plants that produce allelochemicals can be exploited to help manage weeds in cropping systems. Approaches being explored include the use of allelopathic cover crops in rotation with market crops, breeding for allelopathic crop cultivars, and biosynthesis of useful natural herbicides from plants and microorganisms.

Table 2. Cover crops that produce allelochemicals	
Scientific Name	**Common Name**
Avena sativa	Oats
Brassica ssp.	Mustard, radish
Fagopyrum esculentum	Buckwheat
Hordeum vulgare	Barley
Melilotus spp.	Sweet clover
Secale cereale	Cereal or winter rye
Sorghum bicolor	Sorghum
Sorghum bicolor x *S. sudanense*	Sorghum-sudangrass hybrids
Sorghum sudanense	Sudangrass
Trifolium spp.	Clover: red, white, and subterranean
Triticum aestivum	Wheat

Effective species. Many cover crop species produce allelochemicals as they grow *and* during decomposition, meaning that both living cover crops and decaying residue (incorporated or on the surface) can help to suppress weeds. Commonly used cover crops known to produce allelochemicals and effectively suppress weeds are listed in Table x-2. Because these crops also physically suppress weeds, it is difficult to determine if allelopathy is a significant factor in weed control by these species. Despite this unknown, it is generally advantageous to include allelopathic cover crops in crop rotations to promote weed suppression.

Many researchers have documented effective suppression, particularly of small-seeded, broadleaved weeds, by these species. Putman et al. (1983) demonstrated that rye residues reduced the emergence of annual ragweed by 43 percent, green foxtail (*Setaria viridis*) by 80 percent, redroot pigweed by 95 percent, and common purslane by 100 percent. Through a similar study in North Carolina, Worsham and Blum (1992) found that three pigweed species (*A. retroflexus, A. spinosus*, and *A. hybridus*) were controlled by 80 to 100 percent in crops planted into residues of rye or subterranean clover based on weed control ratings.

Considerations. Farmers should be aware of several warnings when using allelopathic cover crops.

- Residues of killed tall fescue (*Festuca arundinacea*), creeping red fescue (*F. rubra*, and perennial ryegrass (*Lolium perenne*), all of which exhibit allelopathy, can significantly reduce crop seedling establishment (Weston, 1990).
- Small-seeded and slow germinating crops are more likely to be adversely effected by allelopathic cover crops than are large-seeded, rapidly germinating crops (Weston, 1996).
- Inhibition of transplant growth by allelopathic cover crops, though not extensively documented, has been observed in woody seedlings grown in a living sorghum-sudangrass cover crop (Geneve and Weston, 1988).

Farmers should select cover crops that can be easily managed and that do not negatively affect seedling establishment to reduce the risk of poor crop germination.

Stale Seedbed Preparation

This weed management strategy consists of preparing a fine seedbed, allowing weeds to germinate (relying on rainfall or irrigation for necessary soil moisture), and directly removing weed seedlings via light cultivation or flame weeding. Seeds or transplants can then be planted into the moist weed-free soil. This technique helps to provide an opportunity for crop emergence and growth before the next flush of weeds. If time allows, this can be done twice before planting. (This strategy for suppressing weeds is discussed in more detail in the "Special Topic" section of this chapter.)

Soil Solarization

Solarization consists of heating the soil to kill pest organisms, including fungi, bacteria, and weed seeds. It also reduces populations of various pathogens and nematodes. Soil is covered in summer with clear or black polyethylene plastic and moistened under the plastic, which is left in place for six to seven weeks or longer. Weed seeds and young seedlings are killed by the heat and moisture and through direct contact with the plastic, which causes scorching.

Research has demonstrated that solarization from July to October with clear or black plastic provides weed control comparable to methyl bromide fumigation in strawberries without reducing fruit yield (Rieger et al., 2001). Solarization can also be used to produce weed–free soil or potting mix for container production in warm climates (Stapleton et al., 2002), and it has been used in Mediterranean climates to reduce weed competition and increase yields of field-grown cauliflower and fennel (Campiglia et al., 2000).

Considerations. In general, solarization is more effective against annual weed species and less effective against perennial weeds. The degree of weed suppression achieved with solarization varies with weed species, depth of seed in the soil, and length of solarization. The drawbacks of solarization include the use of plastics in agriculture and their associated disposal problems (though sheets may be re-used if they are not used as in-season mulch), and the fact that land is taken out of production during the summer.

Guidelines. Solarization can be accomplished on raised beds using a traditional bed layer to lay the plastic, or it can be done on a flat field. Special glues are available to hold the plastic together on a flat field. When solarizing on raised beds, plastic can be left in place and cashcrops planted through it when solarization is complete. To use solarization successfully, farmers should rely on these practices:

- Soil must be finely tilled, and the plastic tarp must fit tightly over the soil.
- Plastic should be from 0.03 to 0.08 inches (0.75 to 2 millimeters) thick, and it should have an ultraviolet inhibitor added to prevent degradation.
- Solarization must be performed during the summer months, due to the temperatures required for effective soil treatment.
- The recommended soil temperatures for solarization are 140°F at a depth of 2 inches and 102°F at a depth of 18 inches (Peet, 1996).

For more details on solarization, see Elmore et al. in the "Recommended Reading" list at the end of this chapter.

Sanitation and Composting

Where do weeds come from? Many on-farm weed populations exist because of the natural movement of weed seeds and propagules from both neighboring and distant populations by wind, animals, people, and other carriers. Human activity is a major culprit in the introduction of weeds to a farm or to new areas on a farm. Paying close attention to sanitation and seed sources on the farm can help prevent the introduction and movement of weeds:

- Clean farm equipment regularly. If machinery and tools are used in more than one location, they should be thoroughly cleaned before use in a different field. Cleaning is especially important when equipment is transferred between farms.

- Limit the amount of off-farm traffic visiting production areas, either by vehicle or foot.
- Apply mulch and compost that is free of weed seeds. Straw mulch, for instance, may contain seeds that will later be a nuisance. To avoid carrying weeds into a field with straw mulch, wet the straw and allow weeds to germinate. Once weed seeds have germinated, dry out the straw bale to kill seedlings by breaking it apart.
- Compost animal manures properly. Animal manures often contain weed seeds, with the source of the manure affecting the number and species of viable weed seeds introduced. To kill weeds and other harmful organisms, compost manures properly before field application. To kill the majority of weed seeds in cattle manure, compost materials at a temperature of at least 180°F (82°C) for no less than three days (Wiese et al., 1998). This temperature is relatively easy to reach in most composting systems.
- Inspect seeds and transplants before planting. Crop seeds, especially grains, may be contaminated with weed seeds. Transplants may have weed seeds in the potting medium if it was not sterilized before use. Buy seeds and transplants from reputable suppliers, and always examine them before planting.

Prevent the Spread of Weeds

1. Clean farm equipment regularly.
2. Apply mulch, compost, and manure that is free of weed seeds.
3. Inspect crop seed and transplants prior to planting.

INCREASING CROP COMPETITIVENESS

Organic farmers can give their market crops a competitive advantage over weeds by choosing the right cultivar and planting it to ensure vigorous growth that outcompetes weeds for light, moisture, and soil nutrients. Mulching the crop can help to ensure vigorous growth and keep weeds from emerging.

Crop Cultivar Selection

Crop cultivars vary in their abilities to compete with and adapt to weeds. Several characteristics can enhance a cultivar's ability to compete with weeds, including its physical structure. Tall grain crops, for example, are generally more competitive with weeds because they intercept light. A large leaf area and high biomass production can also contribute to a cultivar's competitive abilities.

Planting Strategies: Date, Density, and Arrangement

For many row and horticultural crops, rapid growth and early canopy closure can result in the suppression of weeds. For this reason, using transplants when possible for horticultural crop production is advantageous. Use of transplants will increase production costs, so the economic benefit of using transplants must be weighed against cost. When it is economically viable, as is the case with many vegetable crops, use of transplants should be considered.

Research indicates that the planting date, density, and spatial arrangement of a crop can maximize the space it occupies early in the season and put competitive pressure on weeds (Mohler, 2001).

Farmer Profile:
Rex and Glenn Spray

Rex and Glenn Spray have not used herbicides on their farm in Ohio for 25 years. They try to complete two shallow diskings before planting corn almost a full month behind the traditional corn planting date for their climate zone.

In their experience, late tillage is especially effective at controlling early-germinating weeds. The corn germinates more quickly and grows faster than corn planted in mid-April. Rapid emergence of the cash crop results in a competitive advantage over weeds.

In addition, their weed management strategy includes rotary hoeing at weed emergence and cultivations as needed during crop growth. Yields on the Spray farm are consistently equal to county averages.

Planting Date. The optimal planting date for a crop may vary from year to year depending on weather and soil conditions. Although these factors must be considered when a farmer determines a planting date, planting can be timed to limit competition from potentially troublesome weed populations. In some instances, it is wise to seed or transplant a cash crop early to get canopy closure as soon as possible.

Alternatively, some farmers believe that planting on the later side of the window of recommended planting dates makes sense from a weed management perspective. Later planting allows one or two precultivations of weeds, and also can give the cash crop a jump start because of warmer soils.

Crop Density. Many researchers have demonstrated that increasing crop density decreases weed competition, though this strategy poses several risks. First, lodging and disease may increase in certain crops as crop density increases (Mohler, 1996). Second, increasing the crop density may affect the marketability of some crops. Farmers should examine the trade-off between yield gains due to reduced weed competition and any potentially negative effects on yield. This strategy is best suited to seed crops (such as corn and wheat) and not well-suited to most fruiting crops for which increased plant density reduces fruit size. Higher plant density for row crops also helps to buffer against losses caused by mechanical injury from cultivation.

Arrangement. Theoretically, narrow row spacing decreases weed emergence and growth. Research, however, does not overwhelmingly support this conclusion because of inconsistent results in studies of row spacing and weed populations (Mohler, 2001). If narrow row spacing is possible with available planting and cultivation equipment and if it can be done without negatively affecting yield, it can be tried as a weed management tactic.

Crop Health and Vigor

Healthy, vigorous crops are better competitors with weeds for resources, such as light, water, and nutrients. Some crops are inherently better competitors than others, but farmers who make sure that seedlings and transplants have adequate access to nutrients and water will help their crops overcome weed competition. Careful management of soil fertility is essential for successful weed management. Farmers can unknowingly promote weed populations by careless placement or over-application of nutrients, especially nitrogen.

Applying Mulch

Applying a mulch after planting can offer some benefits in many cropping systems. Mulches reduce weed competition by limiting light penetration and altering soil moisture and temperature cycles. Although black plastic is commonly used as a mulching material, its environmental impacts conflict with the goals of regenerative and sustainable production. Synthesized from petroleum, plastic represents a significant use of nonrenewable fossil fuels. In addition, the disposal of plastic mulch has contributed to current landfill problems throughout the United States. The discussion in this chapter will be limited to organic and reusable or biodegradable inorganic mulching materials.

Organic Mulches. Organic mulches include many materials that can be produced on-farm such as hay, straw, and livestock or poultry bedding. Other materials, such as leaves, composted municipal wastes, bark, and wood chips, may be available from off-farm sources. Farmers must consider both the quantity and type of mulch to be applied, and the cost of the mulch and the equipment needed to manage it.

Cost. In situations that require hauling and applying organic mulches, the use of organic mulches can be cost-prohibitive for farmers. Farmers can reduce the costs of purchasing, hauling, and applying mulch by using these strategies:

- Investigate locally available organic mulches. Municipalities will often deliver organic materials for free because it saves them landfill costs.
- Investigate ways in which mulches can be produced on farm.
- Have organic mulch materials analyzed for both nutrient concentration and potential contaminants such as heavy metals, especially those procured off-farm.
- Consider growing vigorous summer cover crops, such as sorghum-sudangrass and pearl millet, that can be cut during the season to produce hay mulch for on-farm use.
- Leave cover crop residues in place for no-tillage planting.

Benefits and drawbacks. Using organic materials as mulch can help to increase soil organic matter, promote soil biological activity, and enhance soil structure, water infiltration, and aggregate stability. Organic matter is biodegradable and does not contribute to landfill problems. Despite these advantages, however, several drawbacks must be considered:

- Organic mulches high in carbon may temporarily reduce the availability of soil mineral nitrogen as they decompose.
- Allelopathic interactions between mulch materials and the crop are possible.
- Mulches of any type may delay soil warming early in the season. Delayed warming can slow or reduce germination of annually seeded crops or lead to delayed fruit set and harvest in perennial systems. Delaying mulching until two to four weeks after planting or delaying planting can reduce this effect, as can proper cultivar selection.

Quantity. The amount of mulch required for effective weed suppression varies with the type of mulch used. In general, weed suppression improves with increasing mulch thickness and uniformity of distribution. Researchers have examined optimal quantities of various mulching materials. Ligneau and Watt (1995) demonstrated sufficient suppression of annual weed emergence with 3 cm (1.18 in.) of composted materials. Researchers have also evaluated the use of shredded and chopped newspaper as mulch in North Carolina and West Virginia (Monks et al., 1997). Newspaper mulch is generally less expensive than other types of organic mulches for small-scale producers. In West Virginia, a thickness of at least 7.6 cm (3 in.) of chopped newspaper mulch was required to provide 90 percent weed control. Another interesting research result was that chopped newspaper performed better than shredded newspaper for conserving moisture, controlling weeds, and maintaining yield.

Researchers are also investigating how much biomass is needed for effective weed management when cover crops are grown for mulch in no-till systems or to apply to other field. Mohler and Teasdale (1993) suggest that residue levels two to four times the recommended seeding depth for a crop provide sufficient weed control. Other factors, however, also influence the effectiveness of cover crop residues. Weed control is enhanced if residues are intact (rather than chopped or cut) when applied to the field, as this delays breakdown of the mulch material and extends the period of weed suppression. As described earlier, cover crops exhibiting allelopathy may also exhibit greater weed suppression and require lower residue biomass.

Finding the optimal level of cover crop residue may involve on-farm trials of various crops to find the mulch system that is most reliable and effective. Researchers from Virginia Tech suggest that at least 3 tons of cover crop biomass are needed for successful no-till vegetable production (Schonbeck and Morse, 2004). For more information, see the Sustainable Agriculture Network entry in the “Recommended Reading List” at the end of this chapter.

Inorganic Mulches. Several inorganic mulches that are more environmentally friendly than disposable plastics are available. Reusable materials such as black polypropylene mulch can be used for long-term weed management in nurseries and some perennial cropping systems (such as blueberries). Reusable cloth mulch has also been used in lettuce production to promote seed germination and prevent weeds. Research is underway to investigate alternatives to plastic mulch such as degradable plastic mulches and paper mulches.

Degradable plastic mulches are either *photodegradable*, breaking down after 30 to 60 days of exposure to sunlight, or *biodegradable*, broken down by soil microorganisms. Degradable materials do not need to be removed from the field following the growing season, and some may be incorporated into the soil to speed degradation.

Paper mulches will also degrade naturally and can be applied using traditional bed shapers. Paper mulches are typically coated with biodegradable materials to slow degradation and provide color. Because biodegradable plastics and coated papers are incorporated into the soil, farmers must discuss guidelines for use with their organic certifier to ensure that the product they wish to use meets National Organic Plan (NOP) standards.

How they compare. Researchers at Cornell University compared the performance of three coated paper mulches, a biodegradable plastic mulch, and traditional black plastic. They reported that all of the mulch products remained intact throughout the watermelon production season. Paper coated with plant-derived oils (soybean and linseed) was difficult to lay and, in this study, did not provide soil warming or moisture retention like other products tested. Watermelon yields were higher on black plastic and the biodegradable plastic than on coated paper mulch (Rangarajan and Ingall, 2002).

Further study of biodegradable plastics has demonstrated that yields are variable on these products compared to traditional black plastic, though many provide sufficient weed control (Rangarajan et al., 2003). Several companies are working to develop biodegradable plastics that are easy to apply and make holes in for planting and that will provide adequate soil coverage throughout the growing season. Information on alternative mulches derived from field trials conducted by Cornell University is available online at **www.hort.cornell.edu/commercialvegetables.**

Farmer Profile: Anne and Eric Nordell

Anne and Eric Nordell have a 6-acre market garden in Pennsylvania. They combine cover cropping, fallowing, cultivation, and hand weeding to maintain relatively weed-free fields that require a minimal amount of their time for hand weeding in even the most weed-prone crops. The Nordells' system is based on a one-year fallow. Because they have enough land available, they can intensively crop only half of their acreage each year. The other half can be "groomed" for weed-free farming. Their system of cover cropping and fallowing also builds the soil and cycles nutrients.

1. They begin the *fallow year* for a field by seeding rye in the fall after the year's market crop has been harvested. If rye cannot be planted in the fall or if the rye stand is poor, they plant oats in the spring. These covers are mowed repeatedly throughout the spring to create a mulch that is left on the field. As mulch is continually replenished, the germination and emergence of spring weeds diminish.
2. The Nordells plow under this first cover crop after it has put on the bulk of its biomass, but before summer weeds have a chance to produce seed. In Pennsylvania, this is usually at the end of June for rye and in mid-July for oats. Cutting the cover crop at this time means that there's a lot of biological activity in the soil to break down residues, and plowing at this time of year also targets perennial weeds at the weakest point in their life cycle.
3. They compost horse manure before applying it to the field. Composting kills most weed seeds in the manure and does not stimulate weed germination and growth like fresh manures can. They spread the composted manure during the summer fallow period.
4. The next step is to harrow every two to three weeks, which helps dry out perennial roots and prevents the establishment of annual weeds. As a result of this strategy, the Nordells no longer have quackgrass and observe only a few broadleaf weeds, such as pigweeds and common lambsquarters.
5. At the beginning of August, they plant the second winter cover crop. For a market crop like onions, the Nordells plant Canadian field peas because they fix nitrogen and die back over winter. Winter-killed cover crops are easy to incorporate, so an early planting of vegetables can be made in spring. In addition, the ease with which winter-killed crops are incorporated means that the Nordells only need to till the top 2 to 3 inches of soil, which brings fewer weed seeds to the surface than deep cultivation. During the growing season, the Nordells plan for some handweeding or mechanical cultivation.
6. After harvesting the market crop, the Nordells initiate the fallow cycle again by planting rye in the fall. If a field is used solely for spring vegetable production, a summer cover crop (such as sweetclover) is established and mowed several times before fall cover crop planting.

The Nordells report that developing this system has taken several years, but they have successfully reduced human hours devoted to weeding, which was their initial goal. Their system requires additional time for cover crop management, but they feel this is time well spent. In their words, "This integrated approach to weed management allows us to spread the weed control effort over the course of the growing season – to suit our schedule – rather than letting the weeds set the pace" (Nordell and Nordell, 1998).

SPECIAL TOPIC: CULTIVATION PRACTICES FOR ORGANIC CROPS

Contributed by: David W. Monks, Katie M. Jennings, Wayne E. Mitchem

A cropping system that works to prevent weed emergence provides a strong foundation for optimal weed management. Cultivation practices that limit competition from weeds are key parts of such a cropping system. This "Special Topic" insert discusses cultivation practices and other strategies that organic farmers can use to eliminate emerged weeds and prevent the spread of weed seeds and propagules.

Cultivation: An Overview

Cultivation of the soil with a variety of different tools can control emerged weeds and disrupt weed reproduction cycles. Farmers use cultivation to supplement the use of herbicides and as a stand-alone treatment for controlling weeds. It is the basis for weed management programs for vegetables produced conventionally (without no-till practices or plasticulture). For example, in North Carolina, sweetpotatoes and pickling cucumbers are cultivated two to three times per growing season to control weeds.

Research indicates that repeated cultivation can reduce the number of weed seeds in the seed bank (Cardina and Hook, 1989; Chancellor, 1985; Gunsolus, 1990; Johnson and Mullinix, 1995). Under optimum rainfall conditions, 50 percent of the weed seeds in the plow layer germinate within six weeks of cultivation (Bond and Baker, 1990). The time needed to reduce the seed number in the seed bank, however, varies by weed species and tillage history.

Considerations. Cultivation is influenced by soil type, rainfall, and crop canopy characteristics. Friable soils with few or no rocks can be easily cultivated. Rainfall, especially during seasons with above average rainfall, can delay or prevent timely cultivation, making emerged weeds more difficult to control. This can lead to reductions in crop yield and quality. Rainfall can also prevent cultivators from working properly, promote survival of weeds that are uprooted by cultivators, and stimulate rooting at the nodes of weeds such as large crabgrass. Finally, crop canopy characteristics should be considered prior to cultivation because cultivators can damage crops that are in a stage that is not suited for cultivation (for example, sweet potatoes at the vining stage or when sweet corn is more than 18 inches tall).

Timing. The timing of cultivation should be based on the critical weed-free period of the cash crop and the weed species present in the field where the crop is growing. The critical weed-free period is the time during the season that weeds must be controlled to ensure optimum crop yield and quality. Critical weed-free periods vary by crop and weeds (Table 3). That is, some crops are more competitive with weeds than other crops, and some weeds are more competitive than other weeds (Table 4).

Table 3. Critical weed-free periods for selected horticultural crops			
Crop	**Critical Weed-Free Period After Seeding or Planting**	**Weed Species**	**Reference**
Bean, snap	Unifoliate stage to flower	Common cocklebur	Neary & Majek, 1990
Carrot	3 to 5 wk	Purple nutsedge	William and Warren ,1975
Cucumber	2 to 5 wk	Mixture of common lambsquarters, common ragweed and longspine sandbur	Friesen, 1978
Muskmelon	4 to 6 wk 0 to 3 wk	Mixture of two pigweed species Smooth pigweed	Nerson, 1989 Terry & Stall, 1997
Okra	3 to 7 wk	Purple nutsedge	William & Warren, 1975
Squash	4 to 6 wk	Mixture of quackgrass, horsenettle, common lambsquarters, and common ragweed	Mallet & Ashley, 1988
Sweetpotato	2 to 6 wk 0 to 4 wk 1 to 8 wk	Mixture of sicklepod, redroot pigweed and yellow nutsedge Mixture of purple nutsedge, yellow cleome, large crabgrass, threelobe morningglory, spreading dayflower, itchgrass, goosegrass, bermudagrass, and sour paspalum Mixture of green kyllinga, wild poinsettia, common purslane, garden spurge, cogongrass, arrowleaf sida, giant sensitive plant, purple nutsedge and goosegrass	Seem et al., 2003 Talatala et al., 1978 Levett, 1992
Tomato	4 to 5 wk 3 to 5 wk	Mixture of common lambsquarters, common ragweed and longspine sandbur Purple nutsedge	Friesen, 1979 William & Warren, 1975
Watermelon	0 to 6 wk	Large crabgrass	Monks and Schultheis, 1998

Table 4. Competitive ratings for selected weeds (10 = most competitive; 1 = least competitive)	
Weed	**Competitiveness Index**
Amaranth, Palmer	8.7
Apple of Peru	6.4
Cocklebur, common	9.8
Cutleaf groundcherry	6.3
Jimsonweed	7.0
Morningglory, ivyleaf/entireleaf	6.5
Morningglory, pitted	6.5
Morningglory, tall	6.6
Nightshade, Eastern black	7.2
Nutsedge, Yellow	5.3
Nutsedge, Purple	5.1
Pigweed, prostrate	5.5
Pigweed, redroot	8.0
Pigweed, smooth	7.7
Pigweed, tumble	6.2
Prickly sida	4.2
Purslane, common	2.9
Purslane, pink	2.8
Ragweed, common	7.5
Ragweed, giant	9.1
Sicklepod	5.8
Spurge, spotted	3.5
Spurred anoda	6.6
Velvetleaf	6.8
Source: Data gathered from a survey completed by A. Straw, J. Norsworthy, A. S. Culpepper, W.E. Mitchem, D.W. Monks, and K.M. Jennings, University of Tennessee, Clemson University, University of Georgia, and North Carolina State University, cooperating.	

Table 5. Optimum crop and weed size for cultivation tools		
Tool	**Crop Size**	**Weed Size**
Flex-tine weeder	Not emerged	1 inch or less
Rotary hoe	Not emerged	0.5 inch or less
Flex-tine weeder	Emerged	1 inch or less
Rotary hoe	Emerged	0.5 inch or less
Sweep cultivator	2.5 inches and greater	Less than 4 inches
Rolling cultivator	10 inches or less	Less than 2.5 inches
Torsion weeders	10 inches or less	1 inch or less
Basket weeder	10 inches or less	1 inch or less
Finger weeder	Emerged	Less than 1 inch
Flexible finger weeder	Emerged	Less than 1 inch
Mower	Emerged with tall weeds	Weeds taller than crop canopy
Flame cultivation	Various stages depending on crop (see Table 6)	Broadleaf weeds less than 2 inches
Sources: Bowman, 1997; Hotte et al., 2000		

Cultivation Tools for Weed Control

Organic farmers have several options for controlling emerged weeds during the critical weed-free period. These options include hand removal (pulling, hoeing, or cutting), mowing, mechanical cultivation, and flame cultivation. Table 5 lists the cultivation tools that are commonly used for weed control and indicates when they are most effective based on crop and weed size.

Cultivation Before Planting

As previously discussed in this chapter, cultivating a stale seedbed before planting is one way to reduce weed populations. Cultivation may be used to encourage weed emergence and subsequently remove emerged weeds. The success of a stale seedbed approach depends on establishing an advantage in crop growth over weed growth. The time between field preparation and crop planting may be as short as three to four weeks and up to several months.

USDA-ARS researchers reported that in a stale seedbed system, shallow cultivation prior to planting crops gave better control of certain weeds than a nonselective herbicide (Johnson and Mullinix, 1998). In their study, effective results were observed when the plot was prepared for planting approximately four weeks ahead of planting and then shallow-tilled at two weeks prior to planting and again just prior to planting.

Mechanical Cultivation. While any form of shallow tillage may stimulate weed emergence before planting, soil cultivation by an implement that will destroy clods, provide better soil-weed seed contact, and create soil conditions favorable to weed seed germination is desirable. Flex tine weeders, rotary hoes, or power tillers are effective on small weeds.

Figure 2. Field cultivator

Figure 3. High residue cultivator

Figure 4. High-residue cultivator

Flex tine weeders are effective on small weeds at the *white-thread* to cotyledon stage, whereas rotary hoes are effective at the white-thread to 2-inch stage for rotary hoe. The white-thread stage occurs just after weed seed germination when the radical or first root resembles a white thread. Weeds 4 inches or taller and grasses can tolerate cultivation with a flex tine weeder or a rotary hoe. (These tools may also be used after crop seeding if the crop is seeded deep enough to avoid seed disturbance or injury by the implement.) Tillage depth of flex tine weeders is easily adjusted by pressure on the tines or by using gauge wheels (see **ww.hort.uconn.edu/weeds/htms/weeders.html**). The speed of the rotary hoe affects weed control results because increased operation speed reduces soil penetration.

Figure 5. Flex-tine weeder with torsion rods

Figure 7. Flame weeder on tractor

A self-propelled or tractor-mounted rotary power tiller can also be used to kill weeds. Shallow tillage gave excellent weed control in a stale seedbed system at the University of Georgia (Johnson and Mullinix 1995, 1998, 2000). The plant bed was prepared approximately four weeks ahead of planting, tilled two weeks prior to crop planting, and tilled again just prior to cucumber planting. Rotary tillers are very effective in controlling weeds, and depth of tillage can be adjusted easily.

Flame Cultivation. Broadcast flame cultivation prior to seeding the crop can be used effectively on most organically produced crops. It is more effective on a smooth soil surface than a rough or cloddy surface (Smilie et al., 1965). And it is more effective on broadleaf weeds than grasses, but its effectiveness decreases as weeds mature. Grasses and perennial weeds are most tolerant to flaming. Flaming burns grasses and perennial weeds to the soil surface, but sometimes these weeds are capable of regrowth. Seeding or transplanting crops after flame cultivation must be done carefully to prevent soil disturbance that can lead to weed seed germination and establishment.

Figure 6. Broadcast flame weeder

Cultivation After Planting – In-row

Finger Weeders. Finger weeders consist of steel cones fitted with rubber-coated fingers capable of controlling small weeds growing in the crop row. These fingers are ground-driven by hard spike tines located on the bottom of the steel cones. They give good control of small weeds less than 1 inch tall and can be used on established crops until they are approximately 8 to 10 inches tall. Finger weeders generally are very safe for crops and do not reduce crop stand if used properly. They must be used with a sweep cultivator to control weeds across the entire bed.

Flexible spider weeder. Spider weeders consist of a circular disk fitted with flexible wire fingers. They are ground-driven and are very effective in controlling weeds. Because crop stands are often reduced by this weeder, the crop must be established at above-optimum seeding rates when farmers use this tool. If crop stands are not optimum, using this weeder may result in low productivity. Flexible spider weeders must be used with a sweep cultivator to control weeds across the entire bed.

Figure 8. Flexible spider weeder

Cultivation After Planting – Between-row

Torsion weeders. Torsion or spring hoe weeders are made of flat metal strips that control weeds in the white-thread stage and emerged weeds. These weeders not only uproot or clip weeds (or both), but they also move soil over weeds in the crop row, resulting in weed death.

Rod torsion weeders are made of steel rods that are positioned on each side of the row. These rod weeders run shallow under the soil surface and vibrate so that small weeds are uprooted. Torsion weeders are used with rotating spiders that either push the soil away from the crop row or push soil onto the row around the crop. Cultivators fitted with spider weeders and with torsion weeders are aggressive and are suited for many types of soils.

Figure 9. Torsion weeder—two pairs of torsion rods adjusted for twin row cabbage

Sweep cultivation. Sweep cultivation is aggressive and very effective in controlling weeds less than 4 inches tall. The height difference between weeds and the crop allows soil to be moved around the crop to cover small weeds. This cultivator is not a precision cultivator, but a sliding fender or a rolling star-shaped fender will protect crops in the small seedling stage and prevent crop coverage while the soil is being moved by the cultivator. For perennial weeds and large weeds, sequential cultivations spaced approximately 7 to 10 days apart will often increase control. On many cultivators, sweeps can be adjusted to a sharper angle so they till deeply for large weeds, or they can be adjusted to a flat position so that they can till shallowly for small weeds. Sweeps come in different sizes and can be sharpened on the edges to increase control of large weeds.

Rolling cultivators. Rolling cultivators are aggressive and effective in controlling most annual and perennial broadleaf weeds. Rolling cultivators are not very effective, however, in controlling weedy vines or perennial weeds because their long stems interfere with proper turning of the rolling cultivator units. These weed species must be controlled when they are in the seedling stage. Rolling cultivators effectively control weeds near the crop row, and sweep cultivators are often used with rolling cultivators to control weeds between rows.

Figure 10. Rolling unit—two-row unit

Figure 11. Rolling unit plus sweep

Basket weeders. Basket weeders are precision cultivators that can be used to cultivate multiple rows on beds. These weeders consist of two axles, each with rolling wire baskets. The front axle is fitted with a large sprocket, and the back axle is fitted with a small sprocket that causes the back axle to turn at a faster rate than the front axle. This weeder is very effective at controlling small weeds, but it does not control perennial weeds, such as nutsedge, effectively. Basket weeders work best on soils that do not contain rocks or a high percentage of clay, and that are composed primarily of sand, muck, or high organic matter.

Flame cultivation. Some vegetable crops are suited to flame cultivation after they are planted (Table 6). The objective of flame cultivation is to create a temperature high enough to dehydrate or rupture the plant cells so that weed death occurs. Flame cultivation effectively controls most broadleaf weeds, especially those that are less than 2 inches tall. There are three types of flame cultivation — parallel flaming, cross flaming, and middle flaming:

- **Parallel flaming involves** directing burners to the rear so that the flame patterns run parallel with the crop row. Parallel flaming is used when crops lack tolerance to flaming, either because the crop species is susceptible to flaming or because a crop commonly tolerant to flaming is in a susceptible stage.
- **Cross flaming** can be done by directing the burners so that the flame patterns are across the crop row from each other, but not directly across. Burners set directly across from each other can create turbulence and cause flames to damage crop leaves (Diver, 2002). Cross flaming can be accomplished when the crop is in a tolerant stage of growth — when the crop is taller than the weeds, has a woody stem, or both. To increase crop tolerance, a sprayer can be fitted on the flamer to spray water on the crop just above the burners.
- **Middle flaming** uses burners located beneath a hood over the row middle. The hood directs the flame to the row middles but protects the crop. Infrared weeders are similar in principle to flame weeders. With infrared weeders, however, the flame is directed to a ceramic element or steel plate that radiates heat at 1,800 to 2,000°F (Diver, 2002).

Table 6. Suitability of flame cultivation for vegetable crops during selected stages
(Y = Crop can be flamed in this stage; N = Crop is susceptible to damage by flaming and should not be flamed in this stage.)

Crops	Time of Cultivation		
	Pre-emergence	Directed during Season	Spot Treatment
Broccoli	Y	N	Y
Cabbage	Y	N	Y
Cauliflower	Y	N	Y
Cucurbit crops	Y	Y	Y
Garlic	Y	Y	Y
Greens	Y	N	Y
Okra	Y	Y	Y
Onion	Y	Y	Y
Pepper	Y	Y	Y
Potato, Irish/sweet	Y	N	Y
Sweet corn	Y	Y	Y
Tomato/beans	Y	N	Y

Tests have shown that the length of time the plant is exposed to the flame is the main controlling factor in plant damage, rather than the fuel pressure. Therefore, tractor speed is an important consideration in flaming. A good indicator of efficacy is to squeeze a flame-treated leaf between your fingers. If a thumbprint remains, the foliage has been adequately flamed (Diver, 2002). With heavy weed infestations, sequential flaming approximately three to five days apart is more effective and safer for the crop than heavy flaming at slow speed (Smilie et al., 1965).

Hand removal. Hand removal (hoeing, pulling, cutting) effectively controls most small annual weeds. Removal of weeds by the time they are 3 to 4 inches tall will usually result in effective control. At low densities, escaped mature weeds that have produced seeds can be removed carefully from the field when the soil is damp due to rain or dew and then burned if local laws allow it. Care must be taken to prevent seed loss as weeds are being removed from the field.

Mowing. Mowing may also be an option for weed control in low-growing crops such as sweetpotatoes. Approximately 50 percent of North Carolina sweetpotato growers mow weeds such as Palmer amaranth, common cocklebur, sicklepod, common ragweed, and others that extend above the crop canopy. Mowing gives effective control, but care must be taken to mow above the crop without damaging it. In general, it appears that the critical period for weed control is similar for cultivation and mowing. Multiple mowings are required. The first mowing should occur when weeds extend 6 to 10 inches above the crop canopy. After the initial mowing, most lateral branches of weed plants will grow to similar length, resulting in some weeds becoming more competitive with the crop if no further mowing occurs. Weeds should be mowed again as their new branches grow to 6 to 10 inches.

Weeds that Resist Cultivation

Some weeds survive cultivation. Those weeds include nightshades, pigweed species, common and pink purslane and most perennial weeds (such as johnsongrass, purple and yellow nutsedge, bigroot morningglory, and passionflower). Cultivation can spread perennial weeds. For example, nutsedge populations sometimes increase after hand weeding breaks up the root system as the plant is pulled from the soil (Mitchem, personal communication). Table x-7 lists some of these troublesome weeds and the characteristics that allow them to resist cultivation. Table x-8 is an efficacy table that can be used to determine the effectiveness of each cultivation tool on weeds.

Perennial Weeds. Perennial weeds pose a considerable challenge to organic farmers. Some perennial weeds, such as curly dock, perennial sowthistle *(Sonchus arvensis*), and dandelion, rely primarily on seed production. But many others, including wild onion *(Allium vineale*), field bindweed *(Convolvulus arvensis*), hedge bindweed (*Calystegia sepium*]), alligatorweed *(Alternanthera philoxeroides*), purple nutsedge *(Cyperus rotundus*), and yellow nutsedge *(Cyperus esculentus*), rely on vegetative reproduction. Their ability to reproduce vegetatively allows such weeds to persist despite many cultural and mechanical controls and some chemical controls. Their problematic vegetative propagules vary by species and can include stolons, rhizomes, bulbs, creeping roots, and tap roots.

Table 7. Reproductive characteristics that make weeds difficult to control and ways to improve control		
Reproductive Characteristics	**Weeds Exhibiting this Characteristic**	**Strategies To Improve Control**
Roots at nodes	Crabgrass, large	Cultivate prior to rooting at nodes.
Produces rhizomes and/or stolons	Johnsongrass, Bermuda-grass, quackgrass, field bindweed	Cultivate and hand remove many times over the season.
Roots along stem	Nightshade, eastern black Pigweed species	Cultivate and kill when less than 2 inches tall.
Tubers for reproduction	Nutsedge, yellow or purple	Cultivate several times over the season.
Capable of surviving cultivation	Pigweed species	Cultivate and control when less than 2 inches tall.
Succulent, resistant to drying out	Purslane, common or pink	Cultivate, uproot when soil is dry to cause weed to dry out and die.
Establishes in wet areas of fields	Smartweed	Cultivate sequentially.
Capable of re-sprouting from roots	Perennial vines Nightshade, eastern black	Till to move roots to soil surface and cultivate sequentially.

Table 8. Response of selected weeds to methods of cultivation

Weed	**Broadcast**	**In-Row Cultivation**			**Between-Row Cultivation**			
	Rotary hoe	**Finger**	**Hoe**	**Mow**	**Basket**	**Rolling**	**Sweep**	**Flame**
Amaranth, Palmer	G	G	F-G	G	G	G	G	G
Cocklebur, common	G	G	G	G	G	G	G	G
Crabgrass, large	G	F-G	G	P	G	G	G	P
Foxtail, giant or yellow	G	F-G	G	P	G	G	G	P-F
Galinsoga, hairy	G	G	G	F-G	G	G	G	G
Goosegrass	G	F-G	G	P	G	G	G	P
Groundcherry	G	G	G	G	G	G	G	G
Jimsonweed	G	G	G	G	G	G	G	G
Johnsongrass, seedling	G	F-G	G	P	G	G	G	P-F
Lambsquarters, common	G	G	G	G	G	G	G	G
Nightshade, eastern black	G	G	G	G	G	G	G	G
Nutsedge, purple or yellow	P	F	F	P	P	G	G	P-F
Pigweed, redroot or smooth	G	G	G	G	G	G	G	G
Purslane, common or pink	G	G	G	P	G	G	G	G
Sicklepod	G	G	G	G	G	G	G	G
Smartweed, Pennsylvania	G	G	G	F	G	G	G	G
Spurge, spotted	G	G	G	F	G	G	G	G
Key: Poor (P) = less than 70% control. Fair (F) = 70 to 79% control. Good (G) = over 80% control								

ADDITIONAL TOOLS FOR WEED MANAGEMENT ON ORGANIC FARMS

Animal Labor

The integration of animals into an organic farming system offers benefits, such as enhanced nutrient cycling and conservation, effective use of crop residues, and an alternative source of income for the farm (Clark and Gage, 1996). Animals also can be used as effective tools for weed management. In particular, the use of "weeder" geese has seen a revitalized interest. Prior to the advent of chemical herbicides, geese were popular for weed control in cotton. Geese have also been used for weed control in strawberries, melons, beans, asparagus, potatoes, onion, garlic, tomatoes, turnips, and in vineyards, nurseries, and orchards. In North Carolina, geese have been used in bramble fruits, though year-old plants need to be protected from grazing.

Geese Prefer Grass Weeds
Weeder geese will eat immature seedlings of johnsongrass, bermudagrass, crabgrass, and other grass weeds. They will avoid most broadleaved weeds and crops.

Weeder geese are selective grazers and prefer to eat grasses over broadleaved weeds. They will eat immature seedlings of johnsongrass, bermudagrass (*Cynodon dactylon*), crabgrass (*Digitaria* spp.), and other common grass weeds, but tend to avoid broadleaves such as pigweeds and common lambsquarters. Fortunately, they also will avoid most (but not all) broadleaf crops.

To be effective, geese need to be in place when weed grasses emerge because they are most effective at grazing small grasses. Once weeds are removed, geese will forage on crops in the absence of other food sources. They should, therefore, be removed from fields or provided with food. Because geese are selective feeders, populations of weeds that they do not eat may increase. Therefore, geese are best used in combination with other weed management strategies (Wurtz, 1995). Stocking rates vary by crop, field conditions, weed populations, and other factors. Historically, recommendations have ranged from 2 to 10 geese per acre. Higher stocking rates are necessary in crops with sod intercropping. For example, in orchards where the entire floor is sod, stocking rates can be 50 to 80 geese per acre.

White Chinese and African geese are the most effective weeders. In addition, young geese (goslings) make more effective weeders than mature geese because they are more active and consume seedlings at a higher rate. Goslings can be purchased by mail-order in the spring and then sold for meat in December, in time for winter holidays. Geese are generally fit to be in the field at about six weeks old. Because they require shade, water, and protection at night from predators, movable pens should be constructed to manage the flock. Geese also respond to electrical fencing. ATTRA has a free packet of information on using geese for weed management. To contact ATTRA, visit **http://www.attra.org.**

Approved Herbicides

A limited number of natural substances can serve as herbicides on organic farms.

Corn Gluten Meal. The most widely used of these products is corn gluten meal, a by-product of cornstarch production. Corn gluten meal may be applied as a pre-emergence herbicide. Time of application is extremely important, as the gluten must be present when weed seeds germinate to inhibit root formation.

Weeds that Respond to Corn Gluten Meal

- Common dandelion
- Redroot pigweed
- Smooth crabgrass
- Common lambsquarters
- Curly dock
- Black nightshade
- Creeping bentgrass
- Purslane

Weeds affected by corn gluten meal include redroot pigweed, black nightshade *(Solanum nigrum*), common lambsquarters, curly dock, creeping bentgrass *(Agrostis palustris*), purslane, common dandelion *(Taraxacum officinale*), and smooth crabgrass *(Digitaria ischaemum*). Of weeds that have been tested, barnyardgrass *(Echinochloa crus-galli*) and velvetleaf *(Abutilon theophrasti*) are the least susceptible to corn gluten meal (Bingaman and Christians, 1995). Broadleaf species are generally more susceptible than grasses to corn gluten meal. In field studies, weed cover has been reduced up to 84 percent when corn gluten meal was incorporated prior to planting (McDade and Christians, 2000).

Researchers do not recommend incorporating corn gluten meal prior to direct seeding crops, as crop seedling survival is reduced in the presence of this broad-spectrum herbicide. Transplants, however, are not adversely affected by this product (McDade, 1999). An additional benefit of corn gluten meal is its high nitrogen content. Currently, the Organic Materials Review Institute (OMRI) lists commercially available corn gluten meal under the category *corn gluten*.

The suggested application rate is 20 pounds per 1,000 square feet, though farmers should consult product specifications to determine the application rate suited to their production program. Research on corn gluten in a broad range of production systems and in various regions has not yet been conducted. Farmers should try this product and other organic herbicides on a small scale before applying them in large-scale cropping systems.

Contact Herbicides. Several OMRI-certified contact herbicides are also available. The active ingredients of these herbicides include citric acid, garlic, thyme and clove oils, and acetic acid (vinegar). The OMRI maintains the most up-to-date list of commercially available products accepted for use in certified organic production. These materials are listed in the category *nonsynthetic herbicide*s.

The use of vinegar for weed control is growing in popularity, but the making of homemade vinegar solutions is not recommended. Effective weed control requires a highly concentrated acetic acid solution, which may be dangerous to handle. Acetic acid formulations are commercially available, and most are in compliance with the USDA National Organic Standards.

Exercise care when using acetic acid and other natural weed control products, as most are not selective and may damage crops as well as weeds. A recent study of vinegar and clove oil demonstrated that both products provide good control of small-seeded broadleaved weeds, less control of velvetleaf and common ragweed, and were not effective in controlling giant foxtail. When applied at a rate of 60 gallons per acre, a vinegar application of 20 percent vinegar and 80 percent water was needed to achieve 80 percent control of broadleaved species susceptible to this product (Curran et al., 2005).

Another product often identified for use as a contact herbicide is soap. According to the National Organic Standards Board list of approved substances, soap-based herbicides may be used only for farmstead maintenance and on ornamental crops.

WHAT RESEARCHERS ARE DOING

Researchers around the globe are working to refine and expand the weed management tools that serve as alternatives to synthetic herbicides. These strategies include new mechanical technologies, the use of biocontrols (such as natural plant products and soil bacteria), plant breeding to enhance crop competitiveness with weeds, improved models to predict weed populations, and further development of production systems designed to limit weed competition.

Natural Weed Controls

Researchers are investigating the various agents of weed control available in nature: phytochemicals produced by plants that suppress the growth of other plants (allelopathy), soil bacteria that inhibit seedling growth, and insects that prey upon weed seeds.

Phytochemicals. As previously discussed, the phytochemicals in cover crops can be used to suppress weeds (allelopathy). Researchers continue to investigate ways to optimize this interaction. Research is also underway to identify, extract, and synthesize the plant chemicals responsible for suppressing weed growth to create natural herbicides that could be used in organic farming (Duke et al., 2002).

Weed inhibition by bacteria. Deleterious rhizobacteria (DRB) and other soil microbes can suppress weed species. DRB are specific *rhizobacteria* (bacteria that naturally occur in association with crop and weed root systems) that reduce or prevent plant growth. Investigators are currently working to identify DRB that inhibit specific weed species, to study the effects of cropping systems on DRB populations (Li and Kremer, 2000), and to develop procedures by which DRB can be isolated and applied as a biological weed control agent (Hardin, 1998).

Seed predation by insects. Carabid (ground) beetles (Coleoptera: Carabidae) and field crickets (Orthoptera: Gryllidae), for example, have been identified as important seed consumers in temperate climates. These species are found naturally in agricultural production systems. Research is underway to determine the effects of various agricultural practices on the presence and effectiveness of such species in lowering weed populations (Menalled et al., 2000). Existing research suggests that ground beetles may be more abundant on organic farms than on farms that apply synthetic pesticides (Dritschilo and Wanner, 1980). Efforts have been made to identify additional insect species that may be effective in reducing weed populations and to develop appropriate methods of introducing seed predators to agricultural fields. For example, the North Carolina Department of Agriculture Biological Control Program has identified and released a weevil that consumes musk thistle seed.

Breeding for Crop Competitiveness and Weed Suppression

Plant breeding is one way to improve weed management in organic systems. By using crops with increased competitive ability and enhanced weed suppressive qualities, farmers will have yet another advantage over weeds. Crop qualities that promote crop competitiveness include early, rapid establishment in less favorable conditions, crop structures that limit weed access to light and nutrients (such as increased ground cover by vegetative portions) and increased plant hardiness (Lammerts van Bueren et al., 1998).

Breeding can also lead to crop varieties with improved seedling resilience and transplant vigor, particularly in systems that rely on cover crop residue. Efforts to improve cover crops for weed management are also a research priority. Desirable cover crop qualities include increased allelochemical production, early establishment, improved structure, complete natural dieback, self-seeding, and high biomass, all of which may be introduced through plant breeding (Foley, 1999).

System-level Approaches to Weed Management

Perhaps the most promising and practical area of research in weed management is the study of agricultural systems. Farming systems can be designed to integrate the various cultural practices that farmers use to manage weeds, such as cover crops, crop rotations, increased crop competitiveness, and direct controls. This line of research is based on the recognition that organic agriculture is *holistic* (Barberi, 2002). It relies on many natural processes working in concert to supply nutrients, build soil organic matter, deter pests, and decrease disease incidence. The same is true of weed management: No single solution or isolated practice will reduce weed competition within an organic farming system.

Research groups at many land-grant universities are designing and conducting studies to assist growers in developing their own farm-specific production programs. For example, the Center for Environmental Farming Systems (CEFS) at North Carolina State University is currently conducting a long-term study and numerous short-term studies of cropping systems for horticultural and commodity crops.

This new focus on integrated cropping systems will require both field trials of these systems and accurate models for assessing weed management within a system. Such models must predict both the negative impact of weeds on crop production (as traditional models have done) *and* the impact of crops and cropping systems on weed populations (Bastiaans et al., 2000). Modeling can be used to help farmers make decisions about their cropping systems, avoid potential weed problems, and design the most beneficial systems for their farms.

Weeds as Indicators of Soil Condition

Recognizing that an agricultural production system will never be entirely weed-free, many farmers have sought to find some value and utility in the weeds on their farms. Can weeds serve as indicators of various soil conditions, such as nutrient deficiencies or compaction? Anecdotal evidence suggests that weeds can serve as indicators of some soil conditions, such as low pH (acid soils), high pH (alkaline soils), high nitrogen, low nitrogen, calcium deficiency, severe compaction, and poor drainage (Hill and Ramsay, 1977). Scientific research on this topic, however, is inconclusive. The information gleaned from weeds cannot substitute for analytical tools, such as soil nutrient testing. But it can be useful for preliminary soil assessments. For a complete list of potential indicator species and soil conditions, see Hill and Ramsey (1977) in the "Recommended Reading" list at the end of this chapter.

ADVANTAGES OF ORGANIC PRODUCTION

Despite the fact that many organic farmers and would-be organic farmers cite weeds as a major impediment to farming organically, going organic may naturally reduce weed competition. In a review of recent research on weed population dynamics in organic systems, Ngouajio and McGiffen (2002) conclude that though the number of weed species found in an organic system may be higher, the total weed density and biomass are often smaller in organic systems than conventional systems.

Organic production systems have three key features that can positively affect weed management:

- Greater soil microbe, insect, and plant species diversity. Increased plant species diversity discourages the outbreak of large populations of a single weed species through resource competition and limited niche availability.
- Soil conditions favorable to beneficial microbes. Increased soil microbe and insect populations deplete the weed seed bank through weed seed predation.
- Suitable habitat for beneficial insect populations. Phytophagous insects limit seedling growth by consuming newly emerged weeds.

These conditions take time to develop. The transition from conventional to organic may lead to short-term increases in weed competition when the equilibrium established by conventional production is disrupted. As the transition progresses, a new equilibrium is established in which weed competition is limited. Over the long term, a well-managed organic system may contain natural limits to weed populations, decreasing both the inputs required for weed management and crop losses due to competition.

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OMRI – Organic Materials Review Institute
www.omri.org

CEFS –Center for Environmental Farming Systems
www.cefs.ncsu.edu

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