CHAPTER 6

Weed Management

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In Chapter 5—Weed Biology, we discussed how weeds grow and compete with crops. While there inevitably will be a certain level of weeds, it is the grower's task to make sure that the weeds present do not exceed damaging thresholds that limit crop yields. In this chapter, we will address practical weed management techniques for the organic producer.

Weed management for organic crop production falls into two categories: cultural weed control and mechanical weed control. A third type of weed control using chemicals is another option, but will not be discussed in this manual as organic herbicides are not commonly used on a large scale in agronomic crops.

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Figure 6-1. *Row crop cultivator.*

Cultural weed control

Cultural weed control includes diversifying rotations, delaying planting, changing planting rate, timing of nutrient application, and using cover crops (see Chapter 13 for more information on cover crops). Cultural methods are the first line of defense in weed management.

ROTATION

Diversifying a rotation is the strongest tool against weeds. Over time, using similar planting dates, and cultivation timing will select for weeds that are adapted to these strategies. Varying crops by different planting date (e.g. wheat is planted several weeks before soybean) or growing a perennial crop in rotation with row crops can prevent weeds from adapting to the planting regimen.

Competitive perennial crops such as alfalfa are especially effective in reducing seed banks of annual grasses and broadleaf weeds and in suppressing perennial weeds like thistle. The advantage of alfalfa is that it is harvested three or four times during the growing season which prevents annual weeds from flowering or producing seed and depletes root reserves of perennials. In addition, its continuous cover provides a habitat for animals that consume weed seeds. Cover crops in rotations can also play a role in preventing weed infestations.

Because rotation is so important for organic farmers, we have devoted an entire chapter to the topic in Chapter 2.

Crop seed size

Crop varieties vary in seed size and those with larger seed size often have increased competitiveness against weeds. Large seed mass gives an initial head start to the crop at the time it is most critical. Small-seeded weeds are capable of fast initial growth, but are dependent on photosynthesis and outside nutrients. A large crop seed has its own internal resources and can provide a jump start over weeds under the right conditions. Crop seed size is one of many factors to consider in crop variety selection.

COVER CROPS AND SMOTHER CROPS

Winter cover crops and smother crops are two additions to rotations that can have an effect on weeds. Winter cover crops can occupy the niche that exists after a summer crop is harvested and before the next season's crop is planted. They can displace weeds that might otherwise germinate in the fall or very early spring. Winter rye and hairy vetch residue also has been shown to have allelopathic effects on some germinating weeds, but this effect is short-lived and lasts only until the residue decomposes. See Chapter 13 for more information on the benefits and risks of winter cover crops.

A smother crop is a vigorously-growing crop that growers use to suppress weeds. Generally, a smother crop is not harvested, but plowed down instead. Two examples of summer smother crops used in the Upper Midwest include buckwheat and sudangrass (or sorghum-sudangrass). Smother crops may suppress some perennial weeds, but a perennial crop such as alfalfa grown for two or more years generally will be a better choice to affect perennial weeds in the long-term. The primary risk in

using smother crops is that their effectiveness in weed control may be inconsistent and unpredictable. Additionally, a smother crop such as buckwheat has potential to become a weed itself.

DELAYED PLANTING

Delayed planting is an option in weed management, but it can reduce crop yields. However, for many organic farmers, delayed planting can be the correct choice in highly weed-infested fields. Delaying planting allows for more mechanical weed control operations to be performed prior to crop planting with the prospect of fewer weeds in the crop.

Organic farmers in the Upper Midwest balance the potential yield gains from improved weed control against potential yield losses from delayed planting by planting corn around May 15 and planting soybean between June 1 and June 15. Cool-season crops like small grains or field pea that are planted early in the spring are not likely to benefit from delayed planting.

Delayed planting can reduce populations of early-emerging weed species (Figure 6-3). See Table 5-11 from the previous chapter for weeds that emerge early in the season. Producers need to monitor their fields and be constantly aware of which weed species (see Chapter 7 for weed identification) are present to decide if a delayed planting strategy is warranted. They also need to consider if a potential decrease in yield is justified.

Figure 6-2. *Sorghum-sudangrass grown as a smother crop.*

PRODUCER PROFILE

SMOTHER CROPS

An organic producer from Wadena County uses buckwheat as a smother crop to control Canada thistle and quackgrass. Buckwheat easily reseeds so he notes that control of buckwheat before it goes to seed is important to prevent volunteers. Oats are not a good choice to plant after buckwheat because of the danger of seed contamination by potential buckwheat volunteer plants in oats. Buckwheat can be planted in June at a rate of up to 50 pounds/acre.

A farmer from McLeod County uses sorghum-sudangrass (Figure 6-2) to suppress Canada thistle and quackgrass, but he finds that large-seeded broadleaf weeds like velvet leaf are not effectively controlled. He plants in the middle of June (no later than June 25th) to get a good stand. Sorghum-sudangrass will winter-kill so it can be tilled in the fall or spring. Sorghum-sudangrass is a warm-season crop planted when soils have warmed in June at a rate of 35 to 40 pounds/acre if drilled or at 40 to 50 pounds/acre if broadcast.

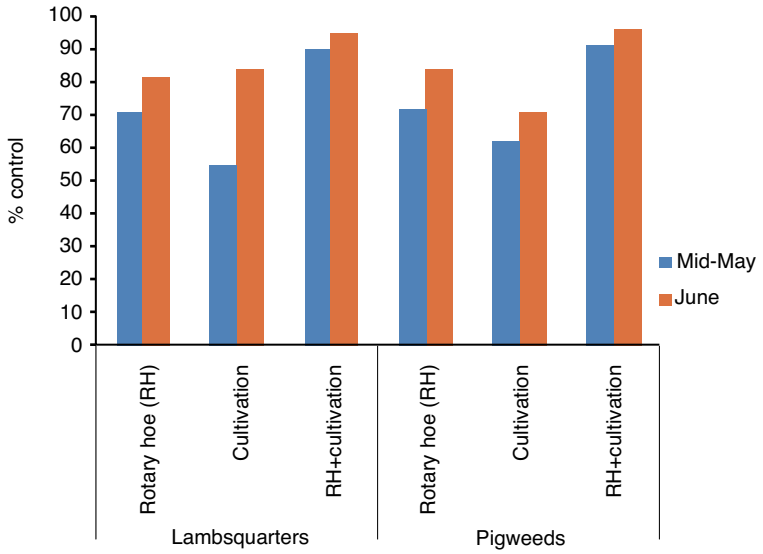

Figure 6-3. ***Effect of delayed planting on control of lambsquarters and pigweeds in soybean, 1989-1991, Rosemount, MN. Soybeans were planted mid-May or early June and treated with the rotary hoe, cultivation or both. Delayed planting usually led to increased weed control, particularly in lambsquarters which emerges earlier than the pigweeds. Adapted from Buhler and Gunsolus, 1996.***

PLANTING RATE

Increasing the planting rate is another common strategy for organic growers. Higher crop densities can lead to greater competitiveness against weeds. In addition, higher planting rates can compensate for crop losses that occur during mechanical weed control operations. The bigger the weed problem, the more effective increasing plant population will be. Less competitive crops like flax may show a greater yield increase. For guidelines as to whether to increase crop plant populations, producers should consult the chapters in this manual for individual crops and with local extension personnel for optimum planting rates for their area.

NUTRIENT APPLICATION

Just as nutrients nourish the crop, they can also nourish the weeds. There are two issues with compost and manure application – how the nutrients affect growth of existing weeds in the field and the potential introduction of new weed seeds. Compost application in the spring can stimulate germination of early-emerging weeds. The growth of many weeds like foxtails, pigweed and lambsquarters is stimulated by nutrients such as nitrogen that are intended for crops (Table 6-1). When weeds have a stronger response to high fertility than the crop does, there will be a negative effect on yield because the weeds will become more competitive and subsequently compete for light and water resources. Examples where this most frequently occurs is with small grains like wheat and barley, which is why applying manure or compost before planting these crops is not recommended. For crops with high nutrient needs, providing proper levels of nutrients can lead to increased competitiveness against weeds.

The timing of fertilizer application can be important. When nutrients are applied too early for crop utilization, weeds may be favored. Producers may be tempted to delay fertilization. However, the unpredictable release of nutrients from organic fertilizers will make using nutrients to manage weeds a challenge.

Table 6-1. Effect of nitrogen on weed growth. Increasing nitrogen levels can have a positive or negative effect on weed growth depending on the species. ***Adapted from Davis, 2005.***

N INCREASES GROWTH	N INHIBITS GROWTH
Velvetleaf	Common ragweed
Foxtail	Canada thistle
Redroot pigweed	
Lambsquarters	
Giant ragweed	
Pennsylvania smartweed	
Eastern black nightshade	
Quackgrass	

The method of manure application can also have an effect on weeds. When manure is injected, nutrients are placed closer to where the crop (instead of weeds) can use them. Broadcast manure application can favor weeds that emerge from shallow depths. If manure is broadcast applied, harrowing the manure into the soil can help place nutrients closer to crop roots.

Manure application can introduce new weed seeds. When livestock consume weed seed, a percentage of it survives digestion and remains in the manure. Broadleaf weeds with large seeds are more likely to survive digestion than are grass or small-seeded weed species. Additionally, livestock bedding such as straw mixed in with manure can be a source of weed seed. To minimize weed introductions from manure, avoid using manure from livestock that graze on weed-infested fields.

Compost will generally have fewer viable weed seeds than manure. Composting manure at temperatures above 140° F for 2 weeks should kill most weed seed. Seed of weeds such as velvetleaf and field bindweed is not killed until temperatures reach 160-180° F. However, under National Organic Plan rules, the minimum temperature for composting is 131° F. Therefore, some weed seeds will still survive under common composting situations, but the overall number of weed seeds will be less than in raw manure. See Chapter 4 – Soil Fertility for more information on composting.

Reducing risk: cultural weed control. Diversify crop rotations as part of a weed management plan. Avoid deep tillage in late spring when using delayed planting; this can stimulate weed germination at the same time the crop germinates. Choose the correct crop planting rate and obtain good stands to make the crop competitive and to compensate for stand loss due to mechanical weed control operations. Time application of amendments to when the crop (not the weeds) needs it most. If manure is known to be from a weedy source, do not apply to "clean" fields with low weed pressure; instead choose a weedy field if there is no other option. Choose composted manure over raw manure to reduce weed seed establishment.

Mechanical Weed Control

In addition to the use of cultural methods to manage weeds, successful organic producers must master the art of mechanical weed control. Effective mechanical weed control is more effective when using a diversity of equipment that provides options to eliminate weeds at different stages of crop growth. Lack of favorable weather or soil conditions to perform a mechanical weed control operation in a timely manner is one of the biggest reasons for failure; thus, the availability of different implements that allow operation under different conditions can reduce risk. Some general guidelines for mechanical weed control are shown in Table 6-2.

Table 6-2. Mechanical weed control guidelines.
Adapted from* Steel in the Field, *2001.

• Go as shallow as possible
• Do as infrequently as possible; every tillage pass reduces soil moisture
• Control should be specific to weed issue
• Limit soil impact
• Know the weed growth stages that are most vulnerable to control practices
• Get weeds when small

Mechanical weed control can be divided into several categories —primary tillage, secondary tillage, and cultivation. Primary tillage and secondary tillage (or seed bed preparation) are performed before the crop is planted. Cultivation occurs after the crop has been planted; examples include pre-emergence and post-emergence broadcast cultivation (blind cultivation without regard for crop rows) before and after the crop has emerged or inter-row cultivation between rows once the crop is at the correct stage of growth. A common mechanical weed control regime for an organic producer in the Upper Midwest in corn and soybean is tillage (fall or spring), seed bed preparation, two rotary hoe or harrow operations after planting and two cultivations when the crop is larger.

The unpredictability of the weather in the spring greatly affects the risk of not getting cultivation accomplished in a timely manner. It is essential to take advantage of favorable weather and soil conditions for mechanical weed control operations. The consequences are that weeds may become too large to control with any type of cultivation.

Total management effects on weeds

In this chapter, we address distinct management options and how they individually affect weeds. In reality, every decision such as rotation or tillage equipment choices made in the field has an interactive effect on weeds. No matter which choices are made, some weeds will be favored over others, resulting in a field's specific weed communities and weed seed bank. These interactions can appear complex so that the effects of each individual choice can be difficult to discern from other effects. Weed scientists are studying these factors in combination with one another. An example is the experiment by Cardina et al.(2002) where weed seed banks under different conventional rotations (continuous corn, corn-soybean, and corn-oats-hay) and tillage systems (chisel and moldboard) were analyzed on a long-term research site in Ohio (Table 6-3). Some of their other findings were:

- Common chickweed and barnyardgrass seeds were lower in moldboard than in chisel.
- Large crabgrass, yellow foxtail, shepardspurse, Pennsylvania smartweed, redroot pigweed seeds were higher in the corn-oats-hay rotation.
- Giant foxtail seed decreased with more complex crop rotations and more tillage.

Table 6-3. Effect of tillage and rotation on weeds in the seed bank (up to 4-inch depths) in Wooster, Ohio, 1997-1999. *Cardina, et al., 2002.*

		FALL PANICUM	GIANT FOXTAIL	LAMBSQUARTERS	TOTAL WEEDS
TILLAGE	ROTATION	SEEDS/FT^2			
Chisel	Continuous corn	15	20	351	527
	Corn-soybean	12	77	566	870
	Corn-oats-hay	43	57	41	957
Moldboard	Continuous corn	<1	2	144	219
	Corn-soybean	9	20	144	246
	Corn-oats-hay	45	22	59	545

A producer from Waseca County who grows corn, soybean, alfalfa, and small grains found that mechanical weed control was one of the most challenging techniques to master when he transitioned to organic farming. Not only does one need to know when is the best time to perform an operation, one needs to account for how weather can prevent performing operations at the optimum time.

PRIMARY TILLAGE

Primary tillage is the initial step in seedbed preparation. It incorporates residues from the previous crop and can incorporate fertilizers. Primary tillage is performed with moldboard, chisel, and disk plows (Figure 6-4). Primary tillage can have a mixed effect on weeds. In the case of weed seeds, it buries some weed seeds so deeply they cannot germinate, but it also brings other seeds to the surface allowing them greater opportunity for germination. For short-lived weed seeds (see Chapter 5), moldboard tillage can bury the seeds and they may die before they can emerge. However, for some weed species, such as velvetleaf and common lambsquarters, deep burial increases seed longevity due to reduced fungal and bacterial activity and lower oxygen levels. For existing weed plants, primary tillage can kill annual weeds and suppress some perennial weeds, but it also can spread vegetative propagules of quackgrass and Canada thistle.

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Figure 6-4. *Chisel plow (above) and disk harrow (below).*

The timing of primary tillage will encourage different weed species to predominate (Table 6-4). Fall tillage promotes winter annual and perennial weeds, while spring tillage promotes spring annual weeds. Often, producers will not have an option as to the best time for primary tillage and what type of equipment they use; what will determine this instead are soil conditions in the spring/fall and soil type suitability for certain equipment.

The type of tillage equipment used can also promote different weed species. Chisel plows will not affect seeds that are below four inches. With chisel plowing, the majority of seeds will remain in the top two inches, while with moldboard plowing, the majority of seeds will end up below two inches in depth. Chisel plowing may favor weeds that germinate from shallow soil depths.

Table 6-4. Species associated with fall and spring tillage. *Weed species associated with spring tillage were usually early germinating and C4 grasses. Weeds associated with fall tillage were late germinating forbs and C3 grasses. Adapted from Smith, 2006.*

FALL	SPRING
Common ragweed	Velvetleaf
Mouse-ear cress	Lambsquarters
Marestail or Horseweed	Redroot pigweed
Quackgrass	Common crabgrass
Common plantain	Stinkgrass
Poa	Fall panicum
Prostrate knotweed	Giant foxtail
Red clover	Green foxtail

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Figure 6-5. *Field cultivator.*

Reducing risk: primary tillage. Be aware of how primary tillage affects existing weeds and weed seed banks. Avoid spreading vegetative propagules of perennial weeds with primary tillage.

SEED BED PREP / SECONDARY TILLAGE

Secondary tillage further breaks up the soil to destroy weeds and prepare the seedbed, and can also work in amendments like compost and manure. Field cultivators, disks, and harrows are used for secondary tillage (Figure 6-5). The timing of seed bed preparation affects which weeds are destroyed. Weeds that emerge early like common lambsquarters are susceptible to seed bed preparation. See Table 5-11 or Chapter 7—Weed Profiles for when different weed species germinate. Thus, early weeds can be controlled by seed bed preparation, while later emerging weeds like pigweeds may have to be controlled at a later date with row crop cultivation.

A fundamental aspect to consider in seed bed preparation is the concept of providing the crop with an "even start." An even start means controlling weeds that germinate before the crop germinates. Once seed bed preparation is complete, the crop must be planted as soon as possible because if crop planting is delayed (even for a matter of hours), weeds can germinate and get a head start on the crop. This can provide a competitive advantage for the weeds and have a larger impact on yields.

Secondary tillage weed control techniques include stale and false seedbeds (Figure 6-6). A stale seedbed is when the soil is left as undisturbed as possible prior to crop planting so weed seeds remain dormant. The goal here is to minimize germination by minimizing soil disturbance. Once the crop is planted, the weeds that do germinate can be controlled through flaming (see later in this Chapter) and in-row (inter-row) cultivation once the crop is at the correct stage. Note that flame weeding is not specific to the stale seedbed technique—it can also be used in combination with the false seedbed technique or other weed control regimens.

The false seedbed is another secondary tillage weed control strategy. With a false seedbed, secondary tillage is used repeatedly to stimulate weed germination and subsequently destroying those seedlings in order to deplete the weed seed bank. Much of the effectiveness of false seedbed practices is dependent on warm

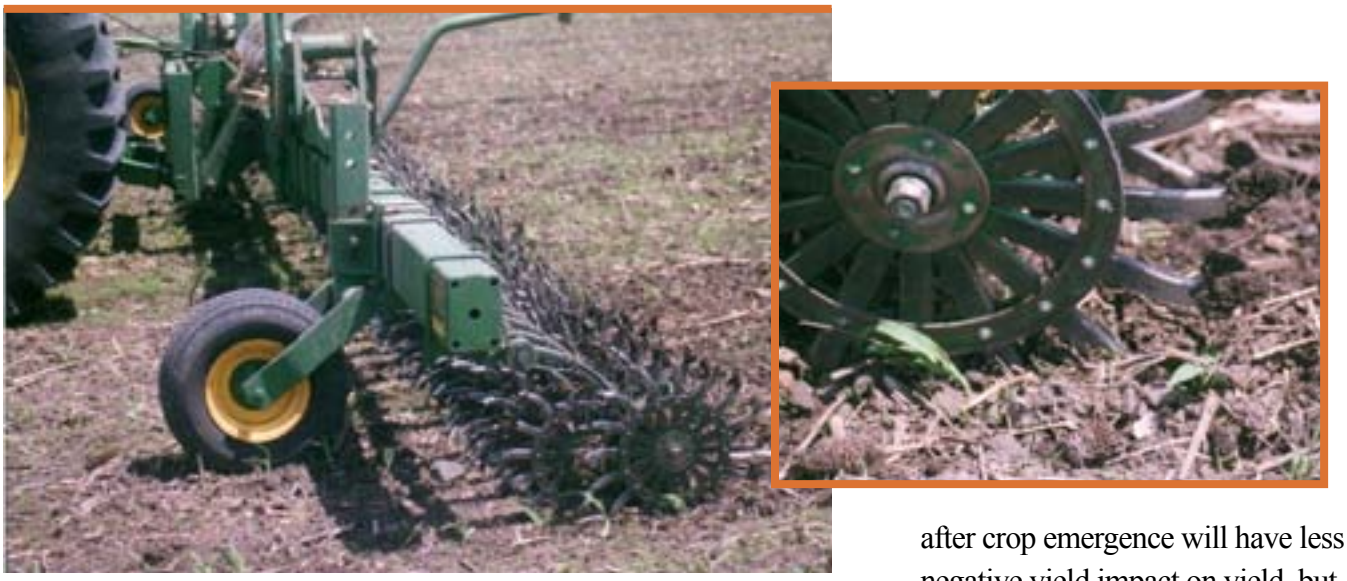

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Figure 6-7. *The rotary hoe has an operating depth of one inch or more.*

seedbed soil temperatures levels to promote a flush of weed seed germination. Secondary tillage depth should be shallow to prevent new weed seeds from being brought up to the surface. The false seedbed technique is commonly used in row crops on organic farms in the Upper Midwest.

Reducing risk: seed bed preparation. Prepare a good seed bed to assure the success of subsequent mechanical weed control operations. Plant as soon as possible after seed bed prep to ensure an "even start". Use a false seedbed approach to deplete seed banks. The effectiveness of the false seedbed approach will be reduced on soils with high levels of crop residues that depress soil temperatures. In addition, excessive tillage on wet and cold soils can cause soil compaction.

CULTIVATION

Row crop cultivating tillage is performed after the crop is planted. Cultivation kills weeds by digging them out, burying them, breaking them apart, or drying them out. In addition to controlling weeds, cultivation can break up soil crusting and thus can increase crop emergence, water infiltration, mineralization of nutrients, and soil aeration.

A short window of time usually exists for timely use of cultivation. Weeds that emerge before or with the crop are the most critical to eliminate. Weeds that emerge after crop emergence will have less negative yield impact on yield, but still may contribute to the weed seed bank for problems in future years. When it comes to weeds that emerge with the crop, it is best to be proactive, rather than reactive. Waiting until weeds are noticeable will limit the control options.

The types of cultivation are broadcast cultivation (blind or full-field cultivation without regard for crop rows), inter-row cultivation (between crop rows), and intra-row cultivation (within crop rows).

Pre-emergence broadcast cultivation Broadcast cultivation can be performed before or after the crop emerges. Pre-emergence

STALE SEEDBED

Delayed or no primary tillage⟶ early planting⟶ flame weeding⟶ cultivation

FALSE SEEDBED

Early primary tillage⟶ repeated shallow cultivation⟶ delayed planting⟶ rotary hoe or harrow 3-4 days post planting⟶ second rotary hoe or harrow operation 3-4 days later⟶ cultivation

Figure 6-6. A comparison of stale and false seedbed techniques.
False seedbed is the more common method for organic farmers in the Upper Midwest.
Adapted from MSU, 2005.

Weed management equipment

In recent years, a resurgence of new and updated implements for mechanical weed control has become available to organic farmers. Choosing new tools (if any) in which to invest can be complicated. Attending field days that demonstrate new equipment and networking with other organic farmers about their experiences are some ways to learn. Below are some additional resources available online that discuss applications of both new and traditional weed management equipment.

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Figure 6-8. *Shovel configuration on a chisel plow used for primary tillage.*

Steel in the Field: A Farmers Guide to Weed Management Tools

This manual, published by Sustainable Agriculture Research and Education, is an excellent resource for investigating the implements used for mechanical weed control. It provides in-depth descriptions and uses of different equipment, as well as farmer's experiences and recommendations. The appendices include a comprehensive list of manufacturers of weed management equipment. This publication is available for free at http://www.sare.org/publications/weeds.htm

New Cultivation Tools for Mechanical Weed Control in Vegetables

This factsheet from Cornell University is geared toward vegetable production, but has good descriptions of cultivation equipment and includes the advantages and disadvantages of various harrows and weeders. Also includes a list of manufacturers. Available at: http://www.vegetables.cornell.edu/weeds/newcultivationmech.pdf

Tillage equipment: Pocket identification guide

This publication from the USDA-NRCS is intended as identification for primary and secondary tillage equipment. Includes many photos with general descriptions of the effects of the implements on soils. http://www.mn.nrcs.usda.gov/technical/ecs/agron/Tillage%20pocket%20guide.pdf

Soil moisture greatly affects the success of rotary hoeing. An organic producer in Lac Qui Parle County says it is preferable to rotary hoe early than to be forced to wait until after a rain. Rotary hoeing is less effective in wet soil.

cultivation is done with chain harrows, flex-tine harrows, spring-tooth harrows, spike-tooth harrows and rotary hoes and affects the top ½ - 1 ½ inches of the soil depending on the equipment (Figure 6-7). These tools are most effective under hot and dry conditions so the up-rooted weeds near the surface will dry out. Pre-emergence cultivation is done three to five days after the crop has been planted. Chain harrows are best for light soils and before crop emergence. Spring-tooth and spike-tooth harrows are aggressive and are best for pre-crop emergence rather than post-emergence. Flex-tine harrows and rotary hoes can be used either pre- or post-emergence (see next section).

Reducing risk: pre-emergence cultivation.

Perform when the soil is dry for maximum weed control. Do not cultivate to a soil depth that is at or below where the crop seed is located.

Post-emergence broadcast cultivation Post-emergence cultivation is an important tool to eliminate weeds that emerge around the same time as the crop. Among the weeds that emerge after planting, these will be the ones that affect crop yield the most. Broadcast or blind cultivation can be performed after the crop has emerged. However, there are several factors to consider such as the type of crop and crop maturity. This type of cultivation has the greatest risk for crop damage and planting rates may need to be increased to compensate for this type of field operation. The best-case scenario for post-emergence cultivation is when the crop is larger than the weeds, which results in the crop being more strongly/deeply rooted and able to withstand the cultivation, and the weeds are smaller and more easily uprooted. Post-emergence broadcast

Table 6-5. Timing by growth stage for rotary hoe operations for individual crops. *Adapted from NDSU.*

CROP	PRE-EMERGENCE	POST-EMERGENCE
Amaranth	Shallow, up to 3-5 days after germination	Not recommended
Buckwheat	Up to 3-5 days after germination	Not recommended
Corn	Up to and including emergence	Emergence to 8 inches tall
Dry Bean	Before crook stage	1-2 trifoliate stage
Field Pea	Epicotyl ½" or more below surface	Emergence to 4 inches tall
Flax	Shallow, up to 3-5 days after germination	Not recommended
Lentil	Epicotyl ½" or more below surface	1-4 inches tall, stand reduction will occur
Oats	Before coleoptile near soil surface	Not recommended
Pearl Millet	Before coleoptile near soil surface	2-6 leaf stage
Proso Millet	Shallow, up to 3-5 days after germination	Not recommended
Sorghum	Before coleoptile near soil surface	Emergence to 8 inches tall
Soybean	Before crook stage	1-2 trifoliate stage
Sunflower	Before hypocotyl emergence	2-6 leaf stage
Wheat, Barley	Before coleoptile near soil surface	1-3 leaf stage

Table 6-6. Timing by growth stage for harrow operations for individual crops. *Adapted from NDSU.*

CROP	PRE-EMERGENCE	POST-EMERGENCE
Amaranth	Shallow, up to 3-5 days after germination	Not recommended
Buckwheat	Up to just before emerging	Not recommended
Corn	Up to and including emergence	Emergence to 8 inches tall
Dry Bean	Before crook stage	1-2 trifoliate stage
Field Pea	Epicotyl ½" or more below surface	Emergence to 4 inches tall
Flax	Shallow, up to 3-5 days after germination	Not recommended
Lentil	Epicotyl ½" or more below surface	1-4 inches tall, stand reduction will occur
Oats	Before coleoptile near soil surface	Not recommended
Pearl Millet	Before coleoptile near soil surface	2-6 leaf stage
Proso Millet	Shallow, up to 3-5 days after germination	Not recommended
Sorghum	Before coleoptile near soil surface	Emergence to 8 inches tall
Soybean	Before crook stage	1-2 trifoliate stage
Sunflower	Before hypocotyl emergence	4-6 leaf stage
Wheat, Barley	Before coleoptile near soil surface	1-3 leaf stage

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Figure 6-9. ***Flex-tine weeder. This tool is becoming more prevalent among organic producers in the Upper Midwest.***

cultivation is performed with rotary hoes and harrows. Timing of these operations is critical—see Tables 6-5 and 6-6 for the recommended crop stages at which to rotary hoe and harrow.

The best time to rotary hoe is when weeds are newly germinated and have reached the "white thread" stage (also called the "white root" or "white sprout" stage). Weeds in the white thread stage have not emerged from the soil. The top inch of soil must be examined to determine if weeds are at the white thread stage. Grass weeds that are past the one-leaf stage or broadleaf weeds that have formed their first true leaves are too firmly-rooted to be controlled with the rotary hoe. However, harrows and tine weeders are more effective on weeds that are somewhat more mature than is the rotary hoe (Figure 6-9). Perennial weeds like Canada thistle, quackgrass, yellow nutsedge or deep-germinating weeds like cocklebur, velvetleaf, wild proso millet, wild oat, and woolly cupgrass are not effectively controlled by rotary hoes or harrows. Rotary hoes, tine weeders, and harrows are more effective on warm, sunny, and windy days, which help dry out small weed seedlings pulled out of the soil by these operations.

Soil type and condition may determine which tool is best for post-emergence cultivation. Rotary hoes are more effective on crusted soils than are harrows or tine weeders. Rotary hoeing is less effective when the soil surface is rough. Tine weeders, harrows and rotary hoes are all hindered by large amounts (greater than 30% coverage) of surface residue (Figure 6-10). Harrows and tine weeders may be more effective on loamy soils than are rotary hoes. Tine weeders have different tines varying in flexibility and thickness that can be used depending on the heaviness of the soil. Rotary hoes are operated at speeds of seven to twelve miles per hour, while harrows are usually operated at speeds between four to six miles per hour.

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Figure 6-10. ***Large amounts of residue can interfere with flex tine weeders.***

An organic producer from McLeod County says timing is the key to managing weeds in his corn and soybean crops. You must get the first weed flush after the crop is planted with a harrow or rotary hoe. The 1st or 2nd cultivation between the rows can be timed to last the rest of the season.

Rotary hoe versus harrow

Organic producers will often have a preference for a type of tillage implement depending on field conditions. A producer from Waseca County prefers the rotary hoe in his soybeans, although he notes that the rotary hoe is less effective on fields with loamy soils and better tilth. Another organic producer from Waseca County does not use the rotary hoe because it misses spots due to his soil, which is highly variable and has an uneven surface. He harrows instead. He cautions that soybeans are more sensitive to harrowing because of their fragile cotyledons at the crook stage. Yet another organic producer from Lac Qui Parle County is moving away from the rotary hoe and has not used it in 4 years. His reasons are that the rotary hoe requires the use of a big tractor, which can cause soil compaction. He can cover the same width with a harrow and a smaller tractor.

Stand losses—post-emergence operations

Once the crop has started growing, any weed control operations performed will have the potential to damage the crop. Crop stand losses due to post-emergence operations like harrowing or rotary hoeing will range from 1% to 25%. Establishing whether weed control operations are too aggressive is an important aspect to maximizing crop yields. To determine stand losses, producers should take a crop stand count prior to and after post-emergent mechanical weed control. This can aid in planting rate decisions and can ensure that the control is not too aggressive.

Frequency of weed control operations should be dependent on weed pressure. Two or three passes for post-emergence control is usually sufficient and additional cultivations can adversely affect crop stand density in addition to adding to cost of production. Even though more weeds are killed with each successive pass, more of the crop is also being killed. There is a tradeoff between the yield loss potential due to weeds and reduced crop stands. A reasonable loss of crop stand per operation should be less than 5%, but experienced organic farmers say if a few crop plants are not being taken out, the operation is not aggressive enough. Once the crop loss for mechanical weed control is estimated, it can be used as a factor to determine what planting rates should be used in subsequent years, assuming the number of weed control operations is similar.

Reducing risk: post-emergence cultivation. **Use the proper equipment for the soil conditions present. Time operations to the correct crop and weed growth stage—see Tables 6-5 and 6-6. Do not use post-emergence cultivation on soybean at the crook stage; it is too fragile.**

Inter-row cultivation Inter-row cultivation controls weeds that grow between the rows, and therefore is only used in row crops (Figure 6-11). Row crop cultivation is secondary to the weed control operations that were performed earlier because the earlier emerging weeds are more critical to control due to their greater potential to reduce crop yield. If the pre- and post-emergence operations were effective, there may be a lag before

PHOTO COURTESY OF JOHN DEERE

Figure 6-11. *Row crop cultivators only affect weeds between these corn rows.*

inter-row cultivations must be done. Inter-row cultivation is done three to five weeks post planting. Tools used for inter-row cultivation include cultivators, rotary tillers, brush weeders, rotary cultivators, rolling cultivators, basket weeders, and rolling harrows.

Inter-row cultivation is low risk to the crop compared to post-emergence broadcast operations. Because cultivation is performed between the rows, the crop should not be directly affected by the machinery. Cultivation is generally performed when the crop is four inches tall and up to the height where equipment will still clear the crop.

Inter-row cultivation is most effective when weeds are not overly mature. Timing of inter-row cultivation is not as critical of an issue as it is for broadcast cultivation. Cultivators can affect weeds up to five inches tall as compared to a rotary hoe which only controls newly germinated weeds. Generally, cultivation is performed at depths less than two inches so that crop roots are not damaged and soil moisture is conserved.

If the young crop is in danger of becoming buried by soil or weeds during cultivation, shields can be used on the cultivator. The goal is to maximize the cultivation area between the crop rows without damaging the crop. Inter-row cultivators also can have modifications that allow soil to be ridged upon the crop row to control within-row weeds. Weeds are buried along with the crop so this method can only be performed on certain crops such as corn and only at certain stages of crop growth.

Organic farmers may need to prove they have effective weed and pest management in order to make an insurance claim. Your organic plan detailing your weed control operations will provide support.

Reducing risk: inter-row cultivation. Do not cultivate too deeply or crop roots can be damaged. Do not rely on inter-row cultivation as your primary method for weed control—use in conjunction with pre- and post-emergence operations.

Intra-row cultivation Intra-row cultivation, also called in-row cultivation, is accomplished through the use of equipment that controls weeds within the crop row. This type of cultivation is more commonly used in horticultural crops, but interest in controlling weeds within a crop row is increasing for those who grow agronomic crops. As mentioned previously, weeds that occur at the same time as the crop can have a great effect on yields and the ones within the crop row are difficult to impossible to control after the crop is past a certain maturity. Equipment for intra-row cultivation is specialized precision tools that include torsion

weeders, spring hoes, spyders, and finger weeders. Intra-row cultivation operations must be done precisely to avoid crop damage and may require the use of electronic guidance systems. One drawback is that this equipment must be operated slower than most other weed control equipment and thus is time-consuming and possibly not viable for large-scale operations. For more information, consult the sources in the "Weed management equipment" Sidebar.

Established perennials

Perennial weeds such as quackgrass or Canada thistle are common weed problems in the Midwest and among the most difficult perennial weeds to manage with mechanical weed control because even small pieces of their rhizomes can generate new plants (Table 6-7). Perennials with deep rhizomes will not be affected greatly by typical weed control operations that are done in the spring. At the same time, perennials with shallow rhizomes will only be affected in the short term by typical seed bed preparation and cultivation and bulbs can typically survive these operations.

Quackgrass and field sowthistle are most susceptible to burying when new shoots are at the three-to-four leaf stage in spring, followed with a second tillage operation. As a last resort, perennial weeds can be controlled by fallow cultivation. Most will respond negatively to repeated cultivation at two to four week intervals (Table 6-8). Another alternative is including perennial crops in rotations. Canada thistle can be controlled by growing alfalfa for three years. A taprooted perennial weed species may be impacted by being buried, while a fibrous-rooted species can be chopped or buried during primary or secondary tillage.

Table 6-7. Equipment effectiveness in managing different perennial weeds. *Tillage for perennial weeds will be more effective when done prior to active growth or flowering to lower plant reserves. Adapted from Liebman et al, 2001.*

WEED SPECIES	GROWTH HABIT	MOLDBOARD PLOW	CHISEL PLOW	FIELD CULTIVATOR
Canada thistle	deep rhizomes	Fair	Poor	Fair
Common milkweed	deep rhizomes	Fair	Poor	Fair
Common plantain	fibrous root	Good	Fair	Fair
Curly dock	taproot	Good	Fair	Fair
Field bindweed	deep rhizomes	Fair	Poor	Fair
Field sowthistle	shallow creeping roots	Fair	Poor	Fair
Nutsedge	bulb	Fair	Poor	Fair
Quackgrass	shallow rhizomes	Fair	Poor	Fair

Table 6-8. Effects of repeated tillage on number of Canada thistle shoots after one year in Lamberton, MN, 2003 and 2004. *Disking to a depth of four to six inches was initiated in May or June and was repeated every three weeks until fall. Repeated tillage significantly reduced the number of thistle shoots after one season in both 2003 and 2004. The number of shoots increased under the corn crop in both years.*

	% thistle shoot change	
TREATMENT	2003	2004
Repeated tillage, May start	-93	-87
Repeated tillage, June start	-96	-93
Corn, one rotary hoe, 2 cultivations	20	110

Flame weeding

Flame weeding is becoming more popular with organic farmers in Minnesota and the Upper Midwest. This technique uses flaming propane burners to rupture the cells of the weeds, which usually die within three days. In row crops, flame weeding is used as a method of directed, within-row weed control (Figure 6-12). However, it can also be used as a broadcast technique, usually prior to crop emergence, which is most suitable when using the stale seedbed technique. Most organic row-crop farmers in the Upper Midwest use flame weeding to control weeds within the crop rows, as they usually have other mechanical options for broadcast weeding that can be performed faster than flame weeding and may be cheaper to operate.

Figure 6-12. *In-row flame weeding.*

When used after the crop has emerged, flame weeding is timed when the crop is at the correct stage so that minimal damage occurs. The proper stage for flame weeding varies by crop—see next sections. Ideal conditions to flame are when the crop is bigger than the weeds. Flaming works best on dry, calm days.

Tractor speed and gas pressure are two components that can be modified to optimize weed kill. The slower the speed and/or the higher the gas pressure will increase effectiveness, but potential crop damage must also be taken into consideration. Typical tractor speeds and propane pressures are in the range of three to five mph and 30 – 40 PSI, respectively. There is no single recommended setting; producers will need to gauge their conditions and make adjustments accordingly. Generally, around seven gallons of propane is used per acre.

Producers gauge effectiveness of each flame weeding operation by using the fingerprint method. Weeds are not burned to a crisp, but instead should show a watermark immediately after the flame weeding when a leaf is pressed (Figure 6-13). Corn will also demonstrate the same effect (Figure 6-14).

The age and type of weeds determine flaming effectiveness. Annual weeds are more vulnerable to flame weeding compared to perennial or biennial weeds. Broadleaves are more susceptible than grasses and broadleaf weeds less than two inches tall are the most susceptible. Flaming is more effective on lambs-

Two organic growers in Waseca County agree that lack of diverse weed control equipment availability can be a risk factor in weed management. Having different equipment provides greater flexibility in timing operations. The tools that they use for their soybean and corn crops include rotary hoes, harrows, flame weeding equipment, and in-row cultivators.

Figure 6-13. *Using the thumbprint method to analyze damage, the weed above has been affected as is shown by the dark spot on leaf where a thumb was pressed. The grass is not visibly burnt, but this indicates the correct level of flaming.*

Figure 6-14. *Fingerprint marking on corn leaf.*

Figure 6-15. *This corn is at the proper stage for flaming. The fourth leaf has not yet developed.*

quarters, chickweed, velvetleaf, and pigweed than on mustards, ragweeds, and grasses. Newly emerged grasses are not much affected because their growing point may still be underground at the time of flame weeding. Weeds that have germinated, but are not yet emerged, will also not be affected by flame weeding. Dust and dew on weed leaves may protect weeds and limit flaming effectiveness. Because flaming does not control grasses well, rotary hoeing or harrowing may be a better option for fields where grasses predominate (Table 6-9). Producers should also be aware that warming the soil with flame weeding may stimulate some weed seeds such as pigweeds to germinate.

Of the agronomic crops commonly grown in the Upper Midwest, only corn and soybean are flamed post-emergence. Flaming in these crops is discussed below.

Table 6-9. A comparison of rotary hoe and flame weeding.
Both tools can be equally effective under the right conditions. Producers can minimize risk by having as many weed control implements as possible at their disposal. Adapted from Mutch et al., 2008.

ROTARY HOE	FLAME WEEDING
Soil type can limit effectiveness	Soil type does not matter
Operation takes less time	Operation takes more time
Can be performed in more crops	Few crops can withstand flaming
Disturbs soil structure	Preserves soil structure
Soil must be dry	Soil can be wet or dry
Effects may be longer lasting	Little residual effect
Cheaper	More expensive; dependent on gas prices
Timing of operation is critical	Timing of operation is critical
Stimulates further weed germination	Does not stimulate weed germination
Windiness increases effectiveness	Windiness decreases effectiveness

FLAME WEEDING CORN

There are two options for flaming once corn has emerged. The first is when the growing point is still below the soil when corn is one to two inches high (Figure 6-15). At this stage, nutrients are still being obtained from the seed. Direct flaming corn after the 4-leaf stage will likely lead to damage of the crop. If necessary, corn at later stages (greater than 10 inches) can be flamed by directing the flame under the leaves and protecting the corn plants using shields.

Corn is the crop least susceptible to damage by flaming because for several weeks after emergence the seed and growing point remain below ground. However, corn will have reduced yields if the timing of flaming is wrong, the speed is too slow (e.g. 1 mph), or if flaming is repeated multiple times. Corn will look damaged after flaming, but it generally has enough reserves to recover if the flaming was timed properly.

FLAME WEEDING SOYBEAN

Organic farmers conduct flame weeding of soybean in Minnesota, but the practice is not as established as it is for corn. Overall, flame weeding in soybean presents a high risk of damage to the crop. If flame weeding is used, it is best before the soybeans emerge or at the crook stage before leaves unfurl (Figure 6-16). Soybeans will be damaged if they are flamed anytime after the crook stage. It is important to be aware that after the crook stage, vegetative development can occur quickly. Sometimes it will only be a matter of hours before the growth stage progresses from safe to a high probability of damage. Flame weeding of soybean is a high risk procedure and should be considered an advanced technique for those with an above-average level of flame weeding knowledge and expertise.

Figure 6-16. *The soybean plant on the left can survive flame weeding, but any growth stage where the cotyledons are no longer protecting the first leaves as in the soybean on the right is susceptible to injury from flame weeding.*

Reducing risk: flame weeding. **Use flame weeding on a smooth and flat seedbed rather than an uneven and cloddy seedbed to lower risk for misdirected flames. If weeds are noticeably burnt immediately after the operation, then the operation was excessive—use the fingerprint method to determine if weeds are damaged. Flame weeding of soybeans is extremely high risk compared to flame weeding of corn. Flame weeding can be potentially dangerous to human and animal health; follow all safety precautions for the use of flammable liquids.**

PRODUCER PROFILE

Flame weeding in Faribault County

An organic grower in Faribault County has been flame weeding successfully for over 30 years. He routinely flame weeds corn, but usually will not flame soybean.

This producer flame weeds corn when it is between 10 to 12 inches tall. When flaming corn at the 10-12" stage, the fire is shot underneath the leaves to minimize corn damage. He cultivates and flames at the same time with the same machine, but he notes that most people flame and cultivate separately.

Cultivation and flame weeding is only possible for him because he flame weeds at a later crop stage. Flame weeding and cultivating at the same time when corn is a few inches tall would result in the cultivation burying the crop seedlings. He flames weeds at about 4 miles per hour at 30 to 35 PSI. He will do one round and gauge damage and then sometimes comes back and flames again a week later.

His biggest weed problems are pigweed, foxtail, and Canada thistle. Due to the perennial nature of Canada thistle, he finds that while thistle will appear damaged after flaming, it will grow back quickly. Foxtail will not be controlled unless it is very small. The flame weeder is just one of many tools he uses for weed control. He also utilizes a harrow, cultivator, cover crops, smother crops, and a diverse rotation.

Rescue operations

Inter-row cultivation is usually the final weed management step for the season. However, when timely weed control operations were not able to be performed, as in cases where weather was uncooperative, weeds can escape. If there are spots where weeds were not adequately controlled, producers can have day laborers hand weed. Another option as a last resort is to till under the portion of a field where weeds dominate.

Reducing risk: rescue operations. Make sure that rescue operations are worthwhile. Remove hand-weeded plants from the field if they have gone to seed so they do not contribute to the seed bank. Organic farmers must be prepared to forfeit part of a crop if weeds get out of control to protect their fields from adding an excessive amount of weed seeds to the seed bank.

Scouting

The contribution of scouting in weed management is often underappreciated. Fields should be checked before mechanical weed control operations begin to ensure that the correct implement is chosen to control weeds at their proper growth stages. Once an operation has been completed, fields should be checked after four or five days or sooner to determine if the procedure was successful and to decide if another operation will be necessary.

An organic producer in Lac Qui Parle County has problems with sunflowers at the edge of one of his fields. He will go in with a hand pruner and cut the flower heads off so the seeds do not remain on the field. Organic farmers need to be sensitive to the impact of adding to the weed seed bank.

A producer from Waseca County says he is constantly scouting anytime he goes out. He recommends that transitioning farmers scout often in order to get a feel for when individual weed species or weed flushes occur to determine when harrowing or rotary hoeing should be done. Otherwise, he says, you will always be playing catch-up. In organic farming when dealing with weeds, you need to be ahead of the game.

Reducing risk: scouting. Write memos about scouting activities. Transitioning producers should scout their fields often to determine patterns of weed emergence. Keep records on weed management practices from year to year and note effectiveness of the various mechanical weed control operations performed. Create weed maps for each field noting location and relative density for each weed species.

Conclusion

This chapter has emphasized the risk in not performing mechanical weed control operations at the optimum time. However, it is important to note that it is possible to perform too many operations. The risk in this is damage to soil structure, crop injury and lowered yields, or unnecessary time and labor spent on redundant operations. Producers should try to strike a balance between controlling weeds and maximizing crop yields. An indispensable component of weed management is scouting for weeds. This includes identifying your weeds and determining when those weeds emerge. Weed operations should be timed to coincide with emergence of your problem weeds. For help in weed identification and weed emergence times, see Chapter 7: Weed Profiles.

JOHN DEERE

Figure 6-17. *Disk harrow.*

Quiz: Weed Management

	Points	Score
1. Which of the following is closest to the rotation you follow?		
Two-year rotation with cover crop	0	
Three-year rotation	1	
Four-year rotation	3	
Five or more year rotation	5	
2. Does your rotation include a perennial crop?		
Yes	5	
No	0	
3. Does your rotation include a cover or smother crop?		
Yes	2	
No	0	
4. Do you ensure that the seed you plant is clean and does not contain weed seed?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
5. Do you plant your crop as soon as possible after seed bed prep, giving the crop an even start?		
Yes, always	5	
Yes, most of the time	3	
No, not really	0	
6. Which of the following describes your view on delayed planting?		
I always plant at a later date regardless of conditions	0	
I sometimes plant at a later date, especially if weeds are heavy	3	
I usually do not plant at a later date	2	
7. If you delay planting, do you know if you have early-emerging weeds (the ones most affected by delayed planting)?		
Yes, I have early-emerging weeds	3	
No, I don't know if I have early-emerging weeds	0	
I do not delay planting	1	
8. Do you adjust your planting rate to accommodate changes in the number of mechanical weed control operations?		
Yes, always	3	
Yes, usually	1	
No, my planting rate is always the same	0	

	Points	Score
9. Which of the following do you primarily use to provide soil fertility?		
Manure	1	
Compost	2	
Green manures	4	
Other amendments	2	
A mix of above	2	
10. Do you time your nutrient application to coincide with crops' needs?		
Yes	3	
No	0	
I don't know	0	
11. Do you apply nutrients only at amounts at which the crops' needs are met?		
Yes	3	
No	0	
I don't know	0	
12. How do you apply compost or manure?		
Broadcast, no incorporation	0	
Broadcast, with incorporation	2	
Injection (manure only)	3	
Not applicable	2	
13. Do you make an effort to ensure that the manure you apply has relatively few weed seeds?		
Yes, always	2	
Yes, most of the time	1	
No, not really	0	
14. Can you identify the specific weeds that occur in your fields?		
Yes	5	
Yes, most of the them	3	
No	0	
15. Do you know at which stage your weeds are most vulnerable to control?		
Yes	5	
Yes, for most of them	3	
No	0	
16. Are you attentive to the timing and density of weed emergence in your fields each year?		
Yes, always	5	
Yes, most of the time	3	
No, not really	0	

continued next page

Quiz: Weed Management

	Points	Score
17. Do you have a diversity of tools for mechanical weed control?		
Yes	5	
No	0	
18. After performing a weed control operation, do you gauge its effectiveness?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
19. Do you gauge how much crop loss is occurring with your mechanical weed control operations?		
Yes, always	3	
Yes, most of the time	2	
No, not really	0	
20. Do you try to account for unpredictable weather conditions when planning mechanical weed control operations for the season?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
21. Do you know when the best time to rotary hoe or harrow for each of the crops you grow?		
Yes	5	
Not sure	0	
22. Do you try to time cultivation to warm, dry conditions?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
23. Do you know how effective different equipment is on perennial weeds?		
Yes	2	
No, not really	0	
24. If you use flame weeding, how do you gauge its effectiveness?		
Weeds show signs of visible burning	0	
Weeds show watermark when pressed with finger	3	
Do not check weeds after flame weeding	0	
Do not flame weed	3	
25. If you use flame weeding, do you flame weed soybean?		
Yes	0	
No	3	
Do not flame weed	3	

	Points	Score
26. Are you prepared to perform rescue operations if weed escapees become dominant?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
27. Do you keep records on your weed management practices and their effectiveness?		
Yes	3	
No	0	
28. Do you scout your fields for weeds before and after weed control operations?		
Yes, always	3	
Yes, most of the time	1	
No, not really	0	
29. Do you feel confident that you are not doing too many mechanical weed control operations?		
My operations are timed to control the weed flushes I know occur in my fields	5	
I always do the same operations regardless of weed pressure	2	
I am not sure	0	
30. Which of the following mechanical weed control strategies do you follow? ***Give yourself 2 points for each strategy.***		
Till or cultivate as shallowly as possible	2	
Till or cultivate as infrequently as possible	2	
Each operation is geared toward specific weed issue	2	
Limit soil impact of weed control	2	
Equipment used is appropriate for weed growth stage	2	
Weeds are targeted when small	2	
31. Which of the strategies do you plan on implementing in the future? ***Give yourself 1 point for each strategy you plan to use from the above list.***		

If your score is:	Your risk is:
76 or greater	Low
36 to 75	Moderate
35 or less	High

TOTAL

FOR MORE INFORMATION

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Weedsoft Yield Loss Calculator – Producers can enter in their crop and weed data and the calculator with figure out the yield losses. http://driftwood.unl.edu/weedsoft/YieldLossCalc/YieldLossOne.php

Steel in the Field: a farmer's guide to weed management tools. http://www.sare.org/publications/weeds.htm

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