PRINCIPLES OF SUSTAINABLE WEED MANAGEMENT FOR CROPLANDS

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Abstract: *To some extent, weeds are a result of crop production, but to a larger extent they are a consequence of management decisions. Managing croplands according to nature's principles will reduce weed problems. And while these principles apply to most crops, this publication focuses on agronomic crops such as corn, soybeans, milo, and small grains. The opportunities to address the root causes of weeds are not always readily apparent, and often require some imagination to recognize. Creativity is key to taking advantage of these opportunities and devising sustainable cropping systems that prevent weed problems, rather than using quick-fix approaches. Annual monoculture crop production generally involves tillage that creates conditions hospitable to many weeds. This publication discusses several alternatives to conventional tillage systems, including allelopathy, intercropping, crop rotations, and a weed-free cropping design. A* ***Resources*** *list provides sources of further information.*

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First, Free Your Brain

As Iowa farmer Tom Frantzen poetically states: "Free your brain and your behind will follow." What Tom is referring to is discovering new paradigms. Joel Barker, author of *Paradigms—The Business of Discovering the Future* (1), defines a paradigm as a set of standards that establish the boundaries within which we operate and the rules for success within those boundaries.

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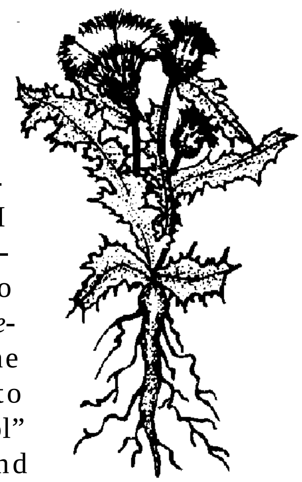


The "weed control" paradigm is *reactive*—it addresses weed problems by using various tools and technologies. "How am I gonna *get rid of* this velvet-leaf?" and "How do I *control* foxtail?" are *reactive* statements. The conventional tools to "get rid of" or "control" weeds—cultivation and herbicides—are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

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

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

The Successful Weed

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

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

Characteristics of a highly successful annual weed include:

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

The Root Cause of Weeds

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

Weeds are evidence of nature struggling to bring about ecological succession. When we clear native vegetation and establish annual crops, we are holding back natural plant succession, at great cost in weed control. To better understand this process, think of succession as a coil spring. Managing cropland as an annual monoculture compresses the spring¾leaving it straining to release its energy as a groundcover of weeds. In contrast, a biodiverse perennial grassland or forest is like the coil spring in its uncompressed condition—a state of relative stability with little energy for drastic change (Figure 1) (2). Generally speaking, biodiversity leads to more stability for the ecosystem as a whole.

Modern crop agriculture is typified by large acreages of a single plant type, accompanied by a high percentage of bare ground—the ideal environment for annual weeds to prosper in the

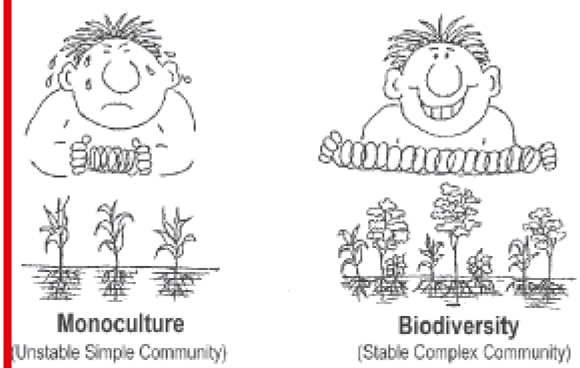


Figure 1.
Monoculture vs. Biodiversity (2).

Weed seed distribution and density in agricultural soils are influenced by cropping history and the management of adjacent landscapes, and may be highly variable. A study of western Nebraska cropland found 140 seeds per pound of surface soil, equivalent to 200 million seeds per acre (3). Redroot pigweed and common lambsquarter accounted for 86%. Growing without competition from other plants, a single redroot pigweed plant can produce more than 100,000 seeds, while a common lambsquarter plant can produce more than 70,000 seeds (4).

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

Survival and germination of weed seeds in the soil depend on the weed species, depth of seed burial, soil type, and tillage. Seeds at or near the soil surface can easily be eaten by insects, rodents, or birds. Also, they may rot or germinate. Buried seeds are more protected from seed-eating animals and buffered from extremes of temperature and moisture. On average, about 4% of broadleaf and 9% of grass weed seeds present in the soil germinate in a given year (5).

Results from seed burial experiments demonstrated that seeds of barnyard grass and green foxtail buried at 10 inches showed germination rates of 34 to 38% when dug up and spread on the soil surface. In the same study, seed buried at one inch showed only one to five percent germination. In another study, seeds were buried at different depths for a period of three years. Seed germination was greater with increasing depth of burial (3). These studies show that seeds near the surface face lots of hazards to their survival, while those buried deeply by tillage are more protected. When those deep-buried seed are plowed up to the surface again they have a good chance of germinating and growing.

Table 1 shows that viable weed seeds are widely distributed in moldboard and ridge-till systems. A higher percentage of seed remains near the soil surface under chisel plow and no-till. The moldboard plow and ridge-till systems are stirring the soil more, burying lots of weed seeds, and keeping weed seed more evenly distributed down to a six-inch depth.

Table 1.
Weed seed distribution with soil depth under four tillage systems (6).

Soil depth (inches)	Moldboard plow	Ridge-till	Chisel plow	No-till
	percent total seed present			
0–2	37	33	61	74
2–4	25	45	23	9
4–6	38	22	16	18

After a seed is shed from the parent plant, it can remain dormant or germinate. There are several different types of dormancy. Seeds with hard seed coats possess "innate" dormancy. Several weed species, including pigweed, have seed coats that require mechanical or chemical injury and high-temperature drying to break dormancy. Another type of innate dormancy can best be described as after-ripening, meaning the seed requires further development after it falls off the plant before it will germinate. Several grass and mustard family weeds require after-ripening (7). "Induced" dormancy results when seeds are exposed to unfavorable conditions, such as high temperatures, after being shed from the parent plant. "Enforced" dormancy occurs when conditions favorable to weed germination are absent. The seeds remain dormant until favorable conditions return. Altogether, multiple types of dormancy ensure that some weed seeds will germinate and some will remain dormant for later seasons.

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

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

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

Proactive Weed Management Strategies

In the preceding sections, we saw how weeds are established and maintained by human activities. So, how do we begin to manage an unnatural system to our best benefit without compromising the soil and water? We can start by putting the principles of ecology to work on our behalf, while minimizing actions that only address symptoms.

Crops that kill weeds

Some crops are especially useful because they have the ability to suppress other plants that attempt to grow around them. *Allelopathy* refers to a plant's ability to chemically inhibit the growth of other plants. Rye is one of the most useful allelopathic cover crops because it is winter-hardy and can be grown almost anywhere. Rye residue contains generous amounts of allelopathic chemicals. When left undisturbed on the soil surface, these chemicals leach out and prevent germination of small-seeded weeds. Weed suppression is effective for about 30 to 60 days (8). If the rye is tilled into the soil, the effect is lost.

Table 2 shows the effects of several cereal cover crops on weed production. Note that tillage alone, in the absence of any cover crop, more than doubled the number of weeds.

Table 2.
Tillage and cover crop mulch influence on weed numbers and weed production (9).

Tillage	Cover Crop	Weeds per foot²	Weed weight lbs. per foot²
Conventional	None	12	.22
None	None	5	.14
None	Rye	0.9	.10
None	Wheat	0.3	.07
None	Barley	0.8	.09

A weed scientist in Michigan (9) observed that some large-seeded food crops planted into rye mulch had high tolerance to the allelopathic effects, while smaller-seeded crops had less tolerance. In the study, corn, cucumber, pea, and snapbean no-till planted under rye mulch germinated and grew as well or better than the same crops planted no-till without mulch. Smaller-seeded crops, including cabbage and lettuce, showed much less germination, growth, and yield. Weeds that were reduced by rye mulch included ragweed (by 43%), pigweed (95%), and common purslane (100%).

Dr. Doug Worsham, a North Carolina weed scientist, concluded that leaving a small grain mulch and not tilling gives 75 to 80% early-season reduction of broadleaf weeds (10). Table 3 shows the results of tillage, mulch, and herbicides on weed control in a tobacco study (11). Just the absence of tillage alone gave 68% grass control and 71% broadleaf control.

Table 3.
Effects of mulch, tillage, and diphenamid herbicide on weed control in tobacco at two North Carolina locations (10).

Treatment	% Broadleaf control	% Grass control
Till no herbicide	8	47
Till + herbicide	52	67
No-till no herbicide	68	71
No-till + herbicide	87	94
No-till + rye, no herbicide	79	80
No-till + rye + herbicide	97	80

In other studies, North Carolina researchers investigated combinations of herbicide use and cover crop plantings on weed control (12). Rye and subterranean clover showed the highest weed control without herbicides (Table 4). Neither provided as much control as herbicides, however. Tillage reduced weed control considerably where no herbicide was used, as compared to no-tillage.

Table 4.
Effect of pre-emergent herbicides, cover crop, or tillage on corn weed control 45 days after planting (12).

Cover Crop	Herbicide	No Herbicide	Herbicide	No Herbicide
	Broadleaf weeds	Broadleaf weeds	Grass weeds	Grass weeds
	percent control			
Rye	100	85	100	79
Crimson clover	100	68	93	68
Sub. clover	100	95	93	75
Hairy vetch	98	18	90	18
No-tillage	99	23	95	20
Tillage	99	0	96	0

By season's end the weed control resulting from cover crops alone had decreased (Table 5). The researchers concluded that additional weed control measures must be applied with cover crops to assure effective weed control and profitable yields.

Table 5.
Effect of cover crop or tillage on corn weed control at harvest (12).

Cover Crop	Broadleaf weeds	Grass weeds
	percent control	*percent control*
Rye	83	36
Crimson clover	41	34
Sub. Clover	66	32
Hairy vetch	10	25
No-tillage	10	19
Tillage	0	0

Other crops that have shown allelopathic effects include sunflowers, sorghum, and rapeseed. Weed control ability varies among varieties and management practices. Sweet potatoes have been shown to inhibit the growth of yellow nutsedge, velvetleaf, and pigweed. Field trials showed a 90% reduction of yellow nutsedge over two years following sweet potatoes (13).

Rapeseed, a type of mustard, has been used to control weeds in potatoes and corn under experimental conditions. All members of the mustard family (Brassicaceae) contain mustard oils that inhibit plant growth and seed germination (14). The concentration of allelopathic mustard oils varies with species and variety of mustard.

Researchers have begun to study ways to manage mustard's weed-suppressive abilities in crop production. In a Pacific Northwest study, fall-planted 'Jupiter' rapeseed and sundangrass were evaluated for suppression of weeds growing in spring-planted potatoes. In the spring, the researchers either tilled or strip-killed the rapeseed in preparation for potato planting. The first year of the study, rapeseed reduced mid-season weed production 85% more than fallowing. By the end of the season, weed production was reduced by 98% with rapeseed, but only 50% the second year. Potato yields are shown in Table 6.

Table 6.
Potato yields following weed treatments over 2 years (14).

Weed Treatment	1992	1993
	cwt/acre	*cwt/acre*
Rapeseed	682	619
Fallow	621	525
Herbicide	658	680

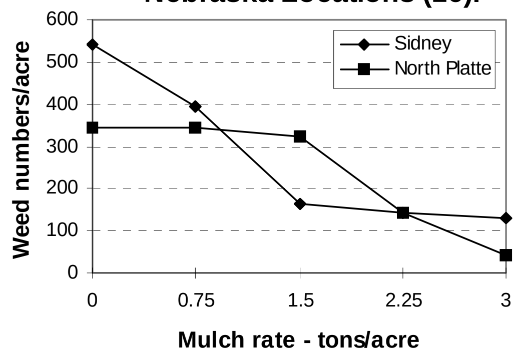
In general, typical levels of cover crop residues, when left on the soil surface, can be expected to reduce weed emergence by 75 to 90% (15). As these residues decompose, the weed suppression effect will decline also. Residues that are more layered and more compressed will be more suppressive (15). Small-seeded weeds that have light requirements for sprouting are most sensitive to cover crop residue. Larger-seeded annual and perennial weeds are least sensitive to residue. Effective management strategies include growing cover crops that produce high amounts of residue, growing slower-decomposing cover crops, packing the mulch down with implements that compress it, and using methods other than cover crops to control large-seeded annual and perennial weeds.

Smother Crops and Mulch

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

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

Figure 2: Weed Levels at two Nebraska Locations (16).



Crop Rotations

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

In a dryland wheat study, continuous winter wheat was compared to a rotation of winter wheat / proso millet / fallow or a winter wheat / sunflower / fallow rotation (17). The year before, at the start of the study, the fields were in winter wheat and were sprayed with Roundup™ (glyphosate) and 2,4-D. The sunflowers were treated with Prowl™ (Pendimethalin). All other weed control was by mechanical means, including a sweep and rodweeder as needed. During the two-year study, weed levels were 145 plants per square yard for the continuous wheat, 0.4 plants per square yard for the winter wheat / proso millet fallow system, and 0.3 for the winter wheat / sunflower fallow system.

Intercropping

Intercropping (growing two or more crops together) can be used as an effective weed control strategy. Having different plant types growing together enhances weed control by increasing shade and increasing crop competition with weeds through tighter crop spacing. Where one crop is relay-intercropped into another standing crop prior to harvest, the planted crop gets off to a weed-free start, having benefited from the standing crop's shading and competition against weeds. Such is the case when soybeans are interplanted into standing green wheat—the thick wheat stand competes well with weeds while the soybeans are getting started. Planting method, planting date, and variety must be well-planned in advance. Though soybeans can be directly drilled into the standing green wheat, less wheat damage occurs if the wheat is planted in skiprows. Skiprows are created by plugging certain drop tube holes in the grain drill. Soybeans can be planted with row units set at spacings matched to the skiprows in the wheat. For example, if the wheat is drilled on 7½-inch rows, to create a 30-inch row spacing for soybeans, every fourth drill hole in the wheat drill would be plugged. Tractor tires will follow the skips, resulting in no damage to the wheat.

Studies in Missouri and Ohio showed that wheat yields were three to six bushels per acre less when intercropped with soybeans than when solid-drilled and grown alone (18). Generally, soybean yields are higher when intercropped into wheat than when double cropped behind wheat in the central and northern Midwest, where double cropping is risky due to a shorter growing season. For more information on intercropping, request the ATTRA publication entitled *Intercropping Principles and Production Practices.*

Weed-Free by Design

Thus far, we've seen that weeds are a symptom of land management that defies nature's design. Stirring the soil with tillage creates conditions favorable for weed germination and survival. Monocultures of annual crops hold natural plant succession back and minimize biodiversity, inviting weed populations to thrive. When we try to maintain bare ground, weeds grow to cover the soil and increase biodiversity.

If we take a proactive approach to the whole agricultural system, rather than just looking at the parts, we can use the principles of nature to our advantage instead of fighting them. We will never win the war against nature, and, she has much more patience than we do. When we try to break the rules of nature, we end up breaking ourselves against the rules.

Let's look at an agronomic system where—by design—weeds simply are not a problem. One of the biggest shortcomings in American agriculture is the separation of plant and animal production. Commodity crop production of corn, milo, and soybeans is really a component of animal production because these crops are largely fed to livestock. It seems inefficient to grow grains separately and haul them to animal-feeding facilities. At Shasta College in Redding, California, Dr. Bill Burrows has developed a series of complementary crop and animal systems. He plants a mixture of milo and cowpeas together, with no herbicide. The milo and cowpeas are so vigorous they outcompete any weeds present. Here nature's principle of biodiversity is obeyed rather than fought with herbicides. Previously, when the milo was grown separately, he had to spray for greenbugs. After he started with the pea-milo mixture, the greenbug problem disappeared. When the milo and peas are mature, he combines them. This produces a milo to pea ratio of 2/3 to 1/3, which is ideal for feed.

After grain harvest he turns his animal mixture of hogs, cattle, sheep, and chickens into the standing crop stubble, thereby adding more diversity. All the waste grain is consumed by livestock, and the stubble trampled into the soil, at a profit in animal gains to the farmer. What few weeds may have grown up with the crop can be eaten by the livestock. Under typical single-crop scenarios, the waste grain would rot in the field and the farmer might incur a $6/acre stalk mowing cost. In this case, following the principle of biodiversity increased profit by lowering cost. Bill and his team designed weeds out of the system. Other opportunities exist to design weeds out of the farming operation. These opportunities are limited only by human creativity—the most underutilized tool in the toolbox.

Reactive Measures

The reactive paradigm of weed management is typified by the word *control*. This word assumes that weeds are already present, or to be expected, and the task is to solve the problem through intervention. Agriculture magazines are chock-full of advertisements promising season-long control, complete control, and control of your toughest weeds. These ads imply that the secret is in the proper tank mix of herbicides. Examining these ads from a cause-and-effect standpoint, we might well conclude that weeds are caused by a deficiency of herbicides in the field.

When selecting a tool for weed management, it helps to understand the weed's growth stages and to attack its weakest growth stage (the seedling stage). Alternatively, management techniques that discourage weed seed germination could be implemented. In so doing, a farmer can identify a means of control that requires the least amount of resources.

The various tools available for weed management fall into two categories: those that enhance biodiversity in the field and those that reduce it (Table 7). This is not to imply a "good vs. bad" distinction. Rather it is meant to describe the effect of the tool on this important characteristic of the crop/weed interaction. In general, as plant diversity increases, weeds become less of a problem.

Table 7. Listing of tools and their effect on biodiversity.

Increase Biodiversity	Decrease Biodiversity
Intercropping	Monocropping
Rotations	Tillage
Cover crops	Herbicides
Strip cropping	Cultivation

Weed Control Tools and Their Effects

Herbicides

Since herbicide information is abundantly available from other sources, it is not covered in detail in this guide. Herbicides can be effective in maintaining ground cover in no-till systems by replacing tillage operations that would otherwise create bare ground and stimulate more weed growth. Until better weed management approaches can be found, herbicides will continue to remain in the toolbox of annual crop production. However, some farmers are realizing that with continued herbicide use, the weed problems just get worse or at best stay about the same. Nature never gives up trying to fill the vacuum created by a simplified bare-ground monoculture, and long-term use of the same herbicide leads to resistant weeds, as they adapt to the selection pressure applied to them. But compared to tillage systems where bare ground is maintained, herbicide use may be considered the lesser of two evils. At least where ground cover is maintained, the soil is protected from erosion for future generations to farm. There are many approaches to reducing costly herbicide use, such as banding combined with between-row cultivation, reduced rates, and using some of the other methods discussed earlier.

Least-toxic Herbicides

Corn gluten meal has been used successfully on lawns and high-value crops as a pre-emergent herbicide. It must be applied just prior to weed seed germination to be effective. A common rate is 40 pounds per 1000 square feet, which suppresses many common grasses and herbaceous weeds (19). Two name brand weed control products containing corn gluten meal are WeedBan™ and Corn Weed Blocker™.

Herbicidal soaps are available from Ringer Corporation and from Mycogen. Scythe™, produced by Mycogen, is made from fatty acids. Scythe acts fast as a broad-spectrum herbicide, and results can often be seen in as little as five minutes. It is used as a post-emergent, sprayed directly on the foliage.

Vinegar is an ingredient in several new herbicides on the market today. Burnout™ and Bioganic™ are two available brands. Both of these are post-emergent burndown herbicides. They are sprayed onto the plant to burn off top growth—hence the concept "burndown." As for any root-killing activity with these two herbicides, I cannot say. The label on Burnout™ states that perennials may regenerate after a single application and require additional treatment.

Researchers in Maryland (20) tested 5% and 10% acidity vinegar for effectiveness in weed control. They found that older plants required a higher concentration of vinegar to kill them. At the higher concentration, they got an 85 to 100% kill rate. A 5% solution burned off the top growth with 100% success. Household vinegar is about 5% acetic acid. Burnout™ is 23% acetic acid. Bioganic™ contains 10% acetic acid plus clove oil, thyme oil, and sodium lauryl sulfate. AllDown Green Chemistry herbicide™ contains acetic acid, citric acid, garlic, and yucca extract. MATRAN™ contains 67% acetic acid and 34% clove oil. Weed Bye Bye™ contains both vinegar and lemon juice. Vinegar is corrosive to metal sprayer parts the higher the acidity, the more corrosive. Plastic equipment is recommended for applying vinegar.

Dr. Jorge Vivanco of Colorado State University horticulture department isolated the compound "catechin," a root exudate from spotted knapweed, *Centaurea maculosa*, that has strong herbicidal properties. Knapweed uses the compound as an allelopathic method of competing with other plants. Several companies are interested in producing an environmentally friendly natural herbicide from the root exudate. Since catechin is naturally occuring, new herbicides made from it may be eligible for EPA's fast-track approval process (21).

Weeder Geese

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

Tillage

Tillage and cultivation are the most traditional means of weed management in agriculture. Both expose bare ground, which is an invitation for weeds to grow. Bare ground also encourages soil erosion, speeds organic matter decomposition, disturbs soil biology, increases water runoff, decreases water infiltration, damages soil structure, and costs money to maintain (for fuel and machinery or for hand labor). Some specific tillage guidelines and techniques for weed management include the following:

- *Preplant tillage*. Where weeds such as quackgrass or johnsongrass exist, spring-tooth harrows and similar tools can be effective in catching and pulling the rhizomes to the soil surface, where they desiccate and die. Discing, by contrast, tends to cut and distribute rhizomes and may make the stand even more dense.

- *Blind tillage*. Blind cultivation is a pre-emergent and early post-emergent tillage operation for weed control. It usually employs either finger weeders, tine harrows, or rotary hoes. These implements are run across the entire field, including directly over the rows. The large-seeded corn, soybeans, or sunflowers survive with minimal damage, while small-seeded weeds are easily uprooted and killed. For corn, the first pass should be made between three and five days after planting and a second at the spike stage. Blind cultivation may continue until the crop is about five inches tall. For soybeans, the first pass should be done when germinating crop seedlings are still about ½ inch below the soil surface, but not when the "hook" is actually emerging. The second pass should be done three to five days after soybean emergence, and twice later at four-day intervals. Sunflowers can be blind-tilled up to the six-leaf stage, giving them an excellent head start on weeds. Grain sorghum may be rotary hoed prior to the spike stage, and again about one week after spike stage. Because the seed is small, timing for blind-till in sorghum is very exacting. Post-emergent blind tillage should be done in the hottest part of the day, when crop plants are limber, to avoid excessive damage. Rotary hoes, not harrows, should be used if the soil is crusted or too trashy. Seeding rates should be increased 5 to 10% to compensate for losses in blind cultivation (22, 23).

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

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

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

Another interesting application of timing to weed control is night tillage. Researchers have found that germination of some weed species is apparently triggered by exposure to light. Tillage done in darkness exposes far fewer seeds to light and reduces weed pressure. So far, small-seeded broadleaf weeds (lambsquarter, ragweed, pigweed, smartweed, mustard, and black nightshade) appear to be most readily affected (24).

Flame weeding

Preplant, pre-emergent, and post-emergent flame weeding has been successful in a number of crops. The preplant application has commonly been referred to as the "stale seedbed technique." After seedbed tillage is completed, weed seeds, mostly in the upper two inches of the soil, are allowed to sprout. Assuming adequate moisture and a minimum soil temperature of 50º F (to a depth of 2 inches), this should occur within two weeks. A fine to slightly compacted seedbed will germinate a much larger number of weeds. The weeds are then "seared" with a flamer, or burned down with a broad-spectrum herbicide, preferably when the populationInsteIn, Instead, the ridge-till planter population is between the first and fifth true-leaf stages, a time when they are most susceptible. The crop should then be seeded as soon as possible, and with minimal soil disturbance to avoid bringing new seed to the surface. For the same reason, subsequent cultivations should be shallow (less than 2 inches deep) (25).

Pre-emergent flaming may be done after seeding, and in some crops post-emergent flaming may be done as well. Flaming is often used as a band treatment for the crop row, and usually combined with interrow cultivation. Early flaming may be done in corn when it is 1.5 to 2 inches high. The growing tip is beneath the soil surface at this stage, and the crop readily recovers from the leaf damage. Subsequent post-emergent flamings may be done when corn reaches 6–10 inches in height, and later at lay-by. No flaming should be done when corn is at approximately 4 inches high, as it is most vulnerable then. The burners are offset to reduce turbulence and to avoid concentrating too much heat on the corn. Water shields are available on some flame weeder models. Uniform seedbed preparation and uniform tractor speed are important elements in flaming. Hot and dry weather appears to increase the efficacy of flaming (26).

Searing the plant is much more successful than charring. Excessive burning of the weeds often stimulates the roots and encourages regrowth, in addition to using more fuel. Flaming has generally proved most successful on young broadleaf weeds. It is reportedly less successful on grasses, as the seedlings develop a protective sheath around the growing tip when they are about 1 inch tall (27). Some concerns with the use of fire include possible crop damage, potential dangers in fuel handling, and the cost of fuel. For more information on flame weeding, see the ATTRA publication *Flame Weeding for Agronomic Crops*.

Integrated Weed Management

An integrated approach means assembling a weed management plan that incorporates a number of tools consistent with farm goals. Included are sanitation procedures, crop rotations, specialized tillage schemes, cover crops, and herbicides. The best examples of integrated approaches have been developed on-farm, by farmers themselves. A useful book that spotlights farmers and other researchers and the integrated weed management strategies they are using is *Controlling Weeds With Fewer Chemicals*, available from the Rodale Institute (see Additional Resources). The next two examples are taken from this book.

Table 8: Approximate Cost of Selected Weed Control Practices - 2003*

Practice/Input	Average per Acre Cost (in U.S. dollars)
Tillage	
Moldboard plow	11.75
Chisel plowing	10.55
Disking – tandem	7.95
Disking offset	9.80
Harrowing	4.60
Soil Finishing	8.90
Field cultivating	7.85
Cultivating – row	6.65
Cultivating – ridge	9.40
Rotary hoeing	5.00
Spraying	
Ground – broadcast	4.60
Ground – incorporated	8.60
Ground – banded	5.05
Aerial	6.15
Rope wick	4.65
Other	
Chopping corn stalks	7.05
Grain drill	9.50
Rye seed (90#/ac)	10.42
Hairy vetch (20#/ac)**	15.00

*Costs of all practices except flaming, rye, and vetch from Iowa Farm Custom Rate Survey averages, Iowa State University Extension publication FM 1698, revised April 2003.
**Hairy vetch seed costs vary widely, ranging from 50¢ to $1.50. 2003 price was 75¢ per pound from Albert Lea Seed house in Albert Lea, MN.

Dick and Sharon Thompson of Boone, Iowa, built a herbicide-free weed-management system around ridge-till technology for corn and soybeans. Fields are overseeded or drilled in the fall with combinations of hairy vetch, oats, and grain rye as a winter cover crop. The vetch provides nitrogen, while the grasses provide weed suppression and erosion protection. The cover crop is not tilled in before planting.

skims off enough of the ridge top to create a clean seeding strip. Subsequent passes with the ridge-till cultivator eliminate any cover crop in the interrow area and help to re-shape the ridges. The Thompsons estimate savings of $45 to $48 per acre using their methods. "Walking the Journey" is a 20-minute video chronicling the Thompson farm, available for $39. See Additional Resources for ordering information.

In Windsor, North Dakota, Fred Kirschenmann has developed a diverse rotation including cool-weather crops like oats, rye, barley, and spring wheat, and warm-season crops like sunflower, buckwheat, and millet. He employs selective timing to manage his principal weed problem, pigeon grass. By planting cool-weather grains early, he can get a competitive jump on the weed, which requires somewhat warmer soil to germinate. The warm-season crops do best long after pigeon grass has germinated, however. He uses shallow pre-plant tillage to control weeds in these crops. Kirschenmann also composts manure before spreading it. One of the many advantages of composting is the reduction of viable weed seeds, which are killed by heat during the curing process.

Don and Deloris Easdale of Hurdland, Missouri, reduced their annual herbicide costs from $10,000 to less than $1,000 in three years on their 300-plus acres of grain crops (28). They use hairy vetch, winter rye, or Austrian winter peas in combination with their ridge-till system. They flail chop hairy vetch or winter peas ahead of the ridge-till planter and plant directly into the remaining cover crop residue. This practice eliminates using a burndown herbicide. The legumes replace much of the nitrogen needed for the corn or milo crop. Some liquid starter and liquid nitrogen is placed below the seed at planting. They more than recover the seed costs of their cover crops in savings on fertilizer and herbicide.

Other ATTRA Publications of Interest

- Cover Crops and Green Manures
  Uses, benefits, and limitations of cover crops and green manures; vegetation management; and sources of information.

- Sustainable Soil Management
  Assessing soil health; organic matter and humus management; organic amendments; soil organisms; aggregation; fertilizers; addtional resources.

- Sustainable Corn and Soybean Production
  Weed, seed, and pest management; strip crop ping; farm experiences.

- Making the Transition to Sustainable Farming
  Planning, key ideas for transitions, and practices.

- Pursuing Conservation Tillage for Organic Crop Production
  A look at the potential for applying conservation tillage to organic cropping systems.

The following Current Topics are also available:

- Conservation Tillage
- Alternative Control of Johnsongrass
- Alternative Control of Field Bindweed

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Additional Resources

Shirley, C., and New Farm staff. 1993. What Really Happens When You Cut Chemicals. February. Vol. 3, No. 2. p. 28–30. 156 p.

This book contains a series of farmers' experiences with adopting new strategies for higher profits and lower input costs, while enhancing the environment. Available for $14.95 from:

Rodale Institute
611 Siegfriedale Road
Kutztown, PA 19530
800-832-6285
610-683-6009
http://www.rodaleinstitute.org
E-mail: ribooks@fast.net

Cramer, Craig, and the New Farm Staff (eds.). 1991. Controlling Weeds with Fewer Chemicals. Rodale Institute, Kutztown, PA. 138 p.

Available for $14.95 from Rodale Institute (see address above).

Bowman, Greg (ed.). 1997. Steel in the Field. Sustainable Agriculture Network Handbook # 2. 128 p.

This book is a farmer's guide to weed management tools using cultivation equipment. Available for $18.00 + $3.95 shipping and handling from the Rodale Institute listed above or:

Sustainable Agriculture Publications
210 Hills Building
University of Vermont
Burlington, VT 05405-0082
802-656-0484
E-mail: sanpubs@uvm.edu
http://www.sare.org/htdocs/pubs/

Walking the Journey: Sustainable Agriculture that Works. 1992.

A 20–minute video of Dick and Sharon Thompson's ridge-till farming in Iowa. Available for $25 from:

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2. Do you know a farmer who is implementing techniques discussed in this publication? Can you provide their address and phone number?

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4. Do you know a good related website not listed in this publication?

5. Please add any other information or comments that you would wish to share.