


Organic/Sustainable Weed Control Hands-On Training Program for Agricultural Educators and Farmers

Project Funded by **Northeast SARE**:
Organic Vegetable Production Weed Control Strategies: Integrating Cultural Practices, Cultivation, Weed Biology and OMRI Herbicides

September 16, 2010
Rutgers University, Snyder Research Farm
140 Locust Grove Road
Pittstown, NJ

October 8, 2010
University of Delaware, Research & Education Center
16483 County Seat Hwy
Georgetown, DE




NORTHEAST SARE
Sustainable Agriculture Research & Education

UD COOPERATIVE EXTENSION
UNIVERSITY OF DELAWARE
College of Agriculture & Natural Resources

RUTGERS
New Jersey Agricultural Experiment Station

Welcome to the University of Delaware's Research and Education Center for the Organic/Sustainable Weed Control Training Program

October 8, 2010

I want to thank everyone for attending this one day training designed to demonstrate many facets of weed management for organic and sustainable vegetable production.

Not all of the practices discussed and demonstrated are acceptable under the USDA National Organic Program. If you are an organic producer or are working with organic producers, be sure you ask your certifier about some of these practices before you implement them on organic fields.

This training is funded by Northeast SARE under a grant entitled: Organic Vegetable Production Weed Control Strategies: Integrating Cultural Practices, Cultivation, Weed Biology and OMRI Herbicides. This grant was written by Dr. John Grande from Rutgers University. John and his colleagues held a similar training at the RU Snyder Research and Extension Farm on September 16, 2010.

Weed control for organic farmers and small fresh market producers is very challenging and there is no one solution for all situations. This program was developed with the goal of exposing you to a range of weed control methods and providing you with an opportunity to try some of these techniques and tools yourself. Also this program was developed to allow sharing of ideas and experiences among the participants.

I would like to thank John Grande for organizing and writing the grant and Ed Dager from RU for sharing his expertise in many of the practices demonstrated and helping to coordinate the training at UD-REC.

This notebook was assembled by Karen Adams and was developed as a reference guide for many of the tools and concepts demonstrated at this workshop. The notebook provides a range of websites and free resources that you can visit and use. Check out these websites for they are always adding additional information.

We will be in touch after the training to get your feedback on this program.

Thanks for coming out and your participation.

Mark VanGessel

WEBSITES USED FOR DEVELOPING THIS NOTEBOOK

ACRES (A Voice for Eco-Agriculture)
www.acresusa.com

Appropriate Technology Transfer for Rural Areas (ATTRA)
www.attra.ncat.org

eOrganic (Organic Agriculture at eXtension)
http://eorganic.info/

Iowa State University Organic Agriculture
http://extension.agron.iastate.edu/organicag

Midwest Organic and Sustainable Education Service (MOSES)
www.mosesorganic.org/

New Agricultural Network
www.new-ag.msu.edu/

Northeast Sustainable Agriculture Research and Education (NE SARE)
http://nesare.org/

Organic Field Crop Production and Marketing in North Carolina
www.organicgrains.ncsu.edu/

Penn State University Organic Agriculture
http://agsci.psu.edu/organic

Rodale Institute (New Farm)
www.rodaleinstitute.org/home




PROGRAM

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16483 County Seat Hwy
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October 8, 2010
9:00 a.m. to 3:00 p.m.




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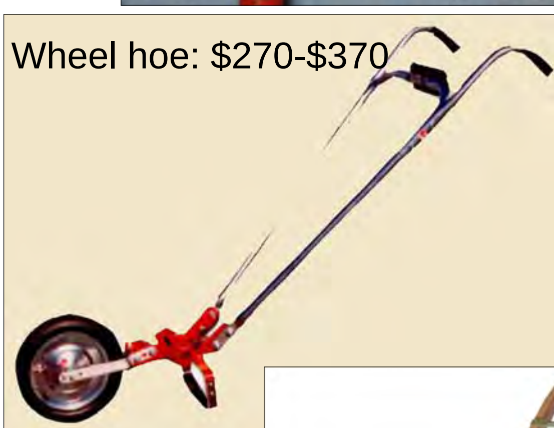
Mark VanGessel
Extension Specialist Weed/Crop Management
mjv@udel.edu

9:15 am to 10:00 am

Hand operated tools and push cultivators for precision weeding of small crops

Small scale organic vegetable farmers in a program planning meeting indicated hand tool weeding was preferred to more costly mechanized equipment.

A variety of hand tools will be demonstrated and discussed.



Wheel hoe: $270-$370

High wheel hoe: $100-$125

Costs of implements range from:

Stirrup hoe:	$28-$46
Collinear hoe	$23-$37
Trapezoid hoe (onion hoe)	$24-$41
Winged weeder	$14-$21
Chopping hoe	$14-$25
Planting hoe	$12
Cultivator—hoe	$ 8-$14
Circle hoe	$25

Backpack flamer $200

10:00 am to 10:45 am

Comparison of straw mulches / plastics / organic mulches for weed suppression

A previous demonstration was initiated on 6/25/10 and included eight mulch applications. Demonstration included: 0 lbs straw/A; 2500 lbs/A; 5000 lbs/A; 7500 lbs/A; and 10,000 lbs/A; and a paper weed barrier plus 5000 lbs straw/A, black plastic mulch with Green Match herbicide sprayed with a 2 nozzle hooded sprayer, and black plastic mulch with two hoeing timings.

Current straw mulch demonstration was initiated on 8/20/10 and includes 0 lbs straw/A; 2500 lbs/A; 5000 lbs/A; 7500 lbs/A; and 10,000 lbs/A; and a paper weed barrier plus 5000 lbs straw/A. The current demo also includes two plots with 5000 lbs/A straw, one with and without nitrogen.

Cost of straw/bale $2-4. Weight of 1 bale ~ 30 lbs. At 7500 lb/A rate = $134-$268 ton/A cost.

Biodegradable mulch (0.6 mil) $369 for 4' by 5000'
Black plastic mulch (1 mil) $92 for 4' by 4000'

Above Left: straw mulch at 5000 lb/A. Above right: straw mulch at 7500 lb/A. Photo taken 5 weeks after initiation date. Note increased weed control in 7500 lbs/A straw plot.

10:45 am to 11:45 am

Comparison of herbicides / flame weeder / sprayer demo

Six herbicides were sprayed on 9/24/10 for demonstration purposes to compare weed control efficacy. Treatments were all sprayed at 40 gpa with a backpack sprayer. Treatments were: 1) Green Match EX; 2) Weed Zap; 3) 20 % Vinegar; 4) 10% Vinegar; 5) Matran EC; 6) BurnOut II. All herbicides included a yucca extract. Aim EW (carfentrazone), a reduced risk pesticide, was also included.

Right: Weed sizes at 9/24 application: Weeds were under severe moisture stress at time of application. Similar treatments at RU Snyder Research Farm provided 100% control.

Left: Weed sizes at 10/5 application: Application made under cloudy conditions.

Herbicide	rate	Cost $/A 40 gpa	Cost $/A 60 gpa
Green Match EX	10%	332	498
Weed Zap	3%	126	189
Vinegar 20%	100%	1,000	1,500
Vinegar 8%	33%	330	495
Matran EC / Matratec	5%	207	310
BurnOut II	33%	340	510
Aim	2 fl oz	16	16

Corn gluten used at low (870 lbs/A) and high (1750 lbs/A) rates cost $1300 to 2700/A. A brand name product "Organic Preen" cost about twice that amount.


solo


shindaiwa
SP415

11:45 am to 12:00 pm

Utilizing cover crops to reduce weed emergence, survival, and competition

The following cover crops were planted on 8/25/10: ryegrass, hairy vetch, sunhemp, forage radish, Japanese millet, buckwheat, cow pea, sorghum sudangrass, Austrian winter pea, and Florida broadleaf mustard.

Demonstration of rye planting method (planted on 9/8/10) includes: 1 bu drilled, 2 bu drilled, 3 bu drilled, 1 bu broadcast plus 2 bu drilled, 2 bu broadcast plus 1 bu drilled and 3 bu broadcast and disked in.

Above photos show rye planted October 2009 and photographed in May 2010. Rye planting date and fertilization has a big impact on final biomass production. October planted rye resulted in a final biomass of 5,200 lbs/A whereas November planted rye produced 3,000 lbs/A biomass.

Left: Side by side comparison of rye planted mid– November at the same seeding rate. Rye on the left was sprayed with nitrogen (30 lbs/A) in the spring and rye on the right had none. Rye with nitrogen produced a final biomass of 2,400 lbs/A compared to rye without nitrogen produced 1,050 lbs/A.

12:00 pm to 12:45 pm

Lunch

12:45 pm to 1:30 pm

Precision cultivation

Tractor mounted cultivation equipment demonstration.


FARMALL


FOBRO


1:30 pm to 2:00 pm

Manipulating soil weed seed bank - various approaches

We will look at various approaches to reduce weed seed germination. These include stale seedbed, till before planting and then plant without disturbing the soil; repeated tillage, exhausting the "germinable" portion of the seedbank prior to planting (false seedbed); using plastic mulches to heat the soil to trigger germination then planting.

1. Last summer we grew sweet corn in a portion of the field and relied on rotary hoeing, cultivation and flaming for weed control;

2. Repeated tillage every 10 to 20 days and did not allow any weeds to produce seeds;

3. Did not till the soil and did not allow any weeds to produce seeds;

Then last fall planted rye in the back half of the area

This summer planted sweet corn early; followed by a later planting of sweet corn or snap beans

Left: 2300 weed seeds in a typical 1 square foot of soil (8 inch depth).

2:00 pm to 3:00 pm

Putting it all together

You are looking at these plots in early August.

What do you intend to do between now and next August.

Choose a crop to work with **(select only one)**:

- Greens
- Peas
- Watermelons
- Sweet corn
- Snap bean
- Pumpkins
- Sweet potato

Please take the time to complete the survey on the last page of this pamphlet. Drop completed survey in the basket on the table or hand to one of the UD staff.

NOTES...

NOTES...

Post-program survey

Organic/Sustainable Weed Control Hands-On Training Program for Agricultural Educators and Farmers
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Please assess your improvement in understanding of the seven competency areas listed below:

Rating scale: 0 to 5
0 indicating lack of impact of training program in this area
5 indicating maximum expected impact from one day training

	Topics	Rate 0-5
1	Hand-operated implements and push cultivators for weeding	
2	Mulching techniques including plastic, straw and other materials to suppress weed competition	
3	Herbicide effectiveness and application techniques	
4	Utilization of flaming for weed control	
5	Influence of cover cropping practices on weed control	
6	Cultivation with tractor mounted implements	
7	Manipulating weed seedbanks; utilization of stale seedbed techniques to reduce weed competition; influence of continuous tillage on reducing weed seed populations	
8	Basic weed biology including weed seed dormancy; weed life cycles; weed population dynamics; weed seed production	

Comments: ______________________________

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Any topics/issues we should have covered?

____

____

Introduction

Organic Weed Control (New Ag Network)

Organic and Sustainable Pest Control (MOSES)

Cultural Weed Control Methods (ACRES)

Principles of Sustainable Weed Management for Croplands (ATTRA)

Organic Weed Management in NC (NCSU)

Weed Management in Organic Cropping Systems (PSU)

Integrated Pest Management Concepts for Weeds in Organic Farming Systems (eXtension)

Knock Weeds Out at Critical Times (eXtension)

Organic farming systems

www.new-ag.msu.edu

New Ag Network
Midwest Organic Team
Fact Sheet 07
July 2009

A researcher using a roller/crimper, kills a cover crop of rye.

Cereal rye plowed under to build soil organic matter levels. The rye also shades the soil and hinders weed seed germination before incorporation.

Organic weed control

Dale R. Mutch

Weeds are the No. 1 concern for field crop organic farmers and pose important problems for vegetable and fruit organic farmers. This is because weeds can dramatically reduce crop yield if they are not managed and controlled. Specific weeds may also provide alternative hosts for insects and pathogens, as well as interfere with harvest either by interfering with machinery or through crop contamination. Organic farmers must use multiple tactics to manage weeds because they cannot use synthetic herbicides, and existing organically acceptable herbicides are costly and primarily limited to burndown activity. For more information see the "Integrated Weed Management" books in the reference section.

Know your weeds

As they say, "Know your enemy." Organic farmers need to pay close attention to what types of weeds are in their fields and how they grow. Know weed life cycles. Are they annual, perennial or biennial weeds? Will the weeds germinate early or mid-summer? How deep in the soil will the seeds germinate? How much seed will the weed produce? Do weeds reproduce vegetatively via rhizomes or stolons? An additional question specific to perennial crops is: Which weeds are problems at time of establishment versus post crop/planting establishment?

Care for your soil

The best line of defense is to build healthy soil. A biologically active and diverse soil will reduce weed populations and help crops grow faster. The faster a crop builds a canopy to fill rows and cover the soil, the less impact weeds will have on the crop. Decreasing weed growth dramatically reduces weed seed production. Healthy soils stimulate weed seed decay and can increase weed seed predation. Healthy soil can be built by using cover crops, choosing good crop rotation, applying compost and other organic soil amendments, maintaining appropriate drainage and reducing compaction. Generally, farmers want to keep weeds out of the field for the first four to six weeks of annual crop growth to maximize crop yield potential.

Commonly used strategies

Here are some of the practices used by organic farmers to reduce weed problems:

- If early weed species such as common lambsquarters or smartweed begin growing, consider allowing these weeds to germinate, then kill them with tillage and delay the crop planting, allowing the crop to get ahead of the weeds.

Rotary hoeing newly emerged soybeans. Gratiot County, MI.

- Increase seeding rates and narrow planting rows to give the desired crop a competitive advantage over weeds.
- Select varieties that will succeed better under organic farming methods.
- For perennial fruit and most vegetable crops, consider using mulches to "smother" weeds. These could consist of wood chips, plastic or fabric weed cloth, living mulches or, in some cases, hay or straw.

Stale seed beds

- Use tillage as a tool to control weeds. Early tillage for seed bed preparation could be moldboard plowing, chisel plowing, field cultivating, rotovating, offset discing or field cultivation. After planting, try rotary hoeing, cultivating or flaming weeds with heat to control weeds.
- Pull, clip and remove weeds when the crops cannot be cultivated. If necessary, hire labor. Since weeds are prolific seed producers, removing these larger weeds can have a positive impact on the weed seed bank in the soil.

This fact sheet has covered the very basics of organic weed control. Below are some excellent references that can be of further assistance.

Recommended resources

1. "Flaming as a Method of Weed Control in Organic Farming Systems." MSU Extension bulletin E-3038. Mutch, D., S.A. Thalmann, T.E. Martin and D.G. Baas. 2008. E. Lansing, Mich. http://web2.msue.msu.edu/bulletins/Bulletins/PDF/E3038.pdf.
2. "Integrated Weed Management: 'One Year's Seeding…'" MSU Extension bulletin E-2931. Davis, A., K. Renner, C. Sprague, L. Dyer and D. Mutch. 2005. E. Lansing, Mich. Michigan State University. http://web2.msue.msu.edu/bulletins/.
3. "Integrated Weed Management: Fine Tuning the System." MSU Extension bulletin E-3065. Taylor, E., K. Renner, and C. Sprague. 2008. E. Lansing, Mich. Michigan State University. http://web2.msue.msu.edu/bulletins/.
4. "Organic Field Crop Handbook." Second edition. Canadian Organic Growers, Box 6408, Station J, Ottawa, Ontario K2A 3Y6. www.cog.ca.
5. Attra. "Field Crops." attra.ncat.org. 800-346-9140.
6. "Organic Weed Control: Cultural and Mechanical Methods." Howell, M. and K. Martens. Acres. August 2002, Vol. 32, No. 8. www.acresusa.com. 800-355-5313.
7. "Organic Weed Management. Organic Field Crop Production and Marketing." Burton, M., R. Weisz, A. York and M. Hamilton. North Carolina State University. www. organicgrains.ncsu.edu/pestmanagement/weedmanagement.htm.
8. "Weed Management in Organic Cropping Systems." Penn State University Extension. Agronomy Facts 64. htttp://cropsoil.psu.edu/extension/facts/agfacts64.cfm.
9. SARE. www.sare.org/publications/all pubs.htm
   a. "Steel in the Field: A Farmer's Guide to Weed Management Tools."
   b. "Managing Cover Crops Profitably," 3rd edition.
   c. "Building Soils for Better Crops," 2nd edition.
10. MOSES. www.mosesorganic.org.

New Ag Network
www.new–ag.msu.edu

The Midwest Organic Team is a division of the New Ag Network. The team consists of researchers, extension educators and certified organic farmers.

Team members:
Dan Anderson, University of Illinois, Urbana-Champaign
Roy Ballard, Purdue University
Andrea Bucholtz, Michigan State University
Matt Grieshop, Michigan State University
Dan Hudson, Michigan State University
Joy Landis, Michigan State University
Dale Mutch, Michigan State University
Ellen Phillips, University of Illinois
Jim True, Purdue University
Dave Campbell, Maple Park, IL
Dale Rhoads, Nashville, IN
John Simmons, North Branch, MI

This project is funded in part with a Professional Development Program grant from NCRSARE.

PESTS

MOSES ORGANIC FACT SHEET

Organic and Sustainable Pest Control

The approach to pest and disease control on organic and sustainable farms is one focused on preventative measures and the reduction of off-farm inputs. The standard agricultural view of pest control often focuses on treating a pest problem once it has already occurred, but given that organic growers do not use synthetic pesticidal products this focus is less effective. Therefore, organic growers take a holistic approach to pest management. This approach is concerned with the entire system and the interactions between the components that make up that system. These methods can potentially reduce dependence on off farm inputs and improve the bottom line.

In order to develop a holistic pest management system we can ask ourselves, what factors on the farm affect pest pressure in some way? Climate and crop identity are going to be the most basic factors in determining what pest issues may arise, while crop diversity is also an important factor. The diversity of crops grown within a year will have important implications for how easily insects move among fields, while crop rotation (or diversity over time), also strongly influences pest distribution. Native biodiversity in non-cropped areas is also important in providing habitat for pest predators and slowing the movement of crop pests, while soil fertility is another factor in enhancing crop resistance to pests.

Climate is a key factor in pest control because it determines the species of crops grown in a region, and therefore the associated pests that growers are going to be dealing with. The most important step farmers can take in terms of climate is to know the life cycle of pests specific to his/her area. This information can help producers to make sound decisions when designing rotations and when monitoring pest pressure throughout the growing season.

Species and variety of the crop will also determine what pests are present. A producer's first consideration is to identify varieties of each crop with genetic resistance to problem pests. Planting resistant varieties can make the rest of your pest management planning much easier because it can effectively prevent pests from becoming a problem.

Another strategy in preventative pest control is managing for diversity. Natural ecosystems contain a community of organisms, and through their interactions, these organisms to work to regulate each other and create a balance in regards to the resources that are available, such as light, water and food. This regulation is the reason that severe pest outbreaks are rare in the natural world. The balance maintained in natural ecosystems is interrupted in an agricultural monoculture, and the response of the ecosystem is to send in insects and weeds to try to restore that balance. This is inevitable and it's the reason farmers have to rely on management to grow a crop. However, if we manage in a way that works to enhance naturally-occurring processes, such as encouraging pest predation by including strips of natural vegetation between fields, we can let the ecosystem do some of the pest control work. Besides providing habitat for pest predators, keeping field sizes from getting to large, growing a number of crops and intercropping when possible can help increase diversity across the farm. Expanding crop rotations and including cover crops not only provide fertility, but diversify the cropping system. In general, a more complex landscape increases habitat for pest predators and can confuse pests, which are unable to travel easily between and within fields. Smaller field sizes (even 50 acres versus 100) have also been shown to increase the mobility of pest predators within the crop, while disease pressure is often reduced by increasing diversity as well.

The organic producers best in-crop defense against pest outbreaks is to ensure crops are healthy and not under stress. Research has shown over and over again that soil fertility and nutrient composition in the plant are related to pest and disease occurrence. Insects and diseases are nature's clean-up crew; they most readily attack plants that are weakened or stressed. So stressed plants are more susceptible to pests and disease, and furthermore, weakened defenses that can occur when a plant becomes diseased can encourage feeding by insects, and feeding by insects can encourage disease! This fact is important in understanding the root causes of pest outbreaks, because outbreaks are often just symptoms of an underlying problem. If, rather than treating the cause of the outbreak, which may be crop stress, we instead address only the symptoms, no ground is gained and we simply continue chasing the pest or disease with new and different "-cides".

Insects are attracted to plants mainly based on chemical "odor" signals given off by the plant, and unhealthy, stressed or diseased plants produce different odors and signals than their healthy counterparts. These distinct odors emanating from unhealthy plants are thought to result from the differing nutrient concentrations within the plant. Soluble fertilizers used in conventional agriculture can at times lead to imbalanced nutrition in plants because nutrients in the fertilizers are readily absorbed by the plant in excess, thereby altering the nutrient profile of the plant. These nutrient imbalances can lead to a metabolic bottleneck where excess simple sugars and free amino acids (simple non-protein nitrogen compounds) accumulate in the plant. The accumulated simple compounds (and their associated odors) are highly attractive to many crops pests because they are easily digestible. For example, excess nitrogen fertilization has been shown to be positively correlated with aphid populations, and research has shown that European Corn-Borer prefers to lay its eggs on plants fertilized with readily soluble synthetic nitrogen fertilizers, as opposed to those fertilized with organic materials. Furthermore, nutritional imbalances prevent a process within the plant called induced resistance. Induced resistance is a remarkable response many plants have to insect feeding. It can lead to the production of odors that attract pest predators, as well as stimulate the production of compounds that make plant tissue distasteful or inedible for insect pests.

It should be noted that simple plant sugars are important building blocks of many plant compounds and a high sugar content is only a problem when the plant is unable to further convert the sugars because of a nutrient imbalance. The bottom line here is that good soil fertility management with a diversity of organic inputs will provide the entire spectrum of nutrients necessary for healthy crops. Crops that will be able to maximize photosynthesis and sugar production, while efficiently making all the secondary compounds that are necessary.

Soils with good fertility and high humus contents also have been shown to suppress many soil borne diseases. Most disease-causing pathogens present in the soil are poor competitors, so this suppression is likely due to competition from a healthy microbial population. However, some direct predation may occur as well.

Even if farmers manage for diversity and do everything they can to ensure that crops are healthy, pest and disease problems are inevitable at some point. In the case of pest outbreaks organic farmers are limited to naturally occurring products, or synthetics approved under National Organic Plan regulations. Organic growers should consult the regulations to view the list of approved synthetic substances, while growers can also consult the Organic Materials Review Institute products list to view a list of approved products. This list can be found online at www.omri.org. It should be noted that companies manufacturing the products on the OMRI list submit their products voluntarily, so just because a product is not on the list does not mean it is not approved. Organic growers should always consult their certifier before applying a new product.

There are many materials that can be used by organic growers to treat pest problems. Some are relatively expensive and therefore are most often used in high value crops. Examples of insecticides include Pyrethrin, a substance naturally occurring in some species of Chrysanthemum, which is effective as a broad-spectrum insecticide ($20-$60/ac), Neem oil (extracted from a tree common in Africa and India) ($20-$50/acre), Spinosad (derived from bacteria, $15-$60/ac) and citrus oils. Diatomaceous earth is inexpensive and can be effective on crawling pests such as insect larva or caterpillars, and applications of the bacterium Bacillus thuringiensis, or Bt, are very effective against insect larvae. Sulfur and copper are allowed for use under organic regulations as fungicides, and sulfur is often mixed with lime to increase its effectiveness. It should be noted that NOP regulations state that these and other reactionary products are only used when preventative measures have failed and a documented pest problem is occurring.

Aside from the above mentioned products, biological controls can be effective in reducing or eliminating pest problems. Biological control consists of the release of insects which prey on crop pests. Beneficial predatory insects include aphid midges, which prey on over 60 species of aphids, lacewings, which are voracious consumers of aphids, thrips, leafhoppers and other vegetable pests, and Trichogramma wasps, which are effective against corn borer and earworms. Many other insects are available as well. These insects usually have to be replenished at certain intervals, but do demonstrate good control in many situations.

Ultimately, farmers will never be completely free from pest problems. Even where crops are healthy and there is diversity in the cropping system pests and diseases will find a way in. Still, if farmers use some simple techniques, such as providing natural vegetation for pest predator habitat, using expanded crop rotations and growing a diversity of crops, and providing fertility through organic sources pest problems can be prevented to a great degree. In fact, after the initial transition period, many organic growers report reduced pest control costs while maintaining comparable yields.

-updated January 2010

Cultural Weed Control Methods

Controlling Weed Propulations Before They Become a Problem

by Mary-Howell & Klaas Martens

"In living nature, nothing happens which is unconnected to the wholes."
— Johann Wolfgang, on Goethe

Demand for organic soybeans, corn and other grains is increasing dramatically worldwide. These organic grains are used directly as human food or fed to organic animals. At the same time, organic production is also rapidly increasing. Because the organic human food market has become considerably more discerning, it is no longer sufficient to simply produce organic crops. It is now essential that organic farmers learn how to produce superior quality organic crops. It is possible to consistently produce food organically that is far better quality and more nutritious than conventionally produced food.

As farmers learn organic practices, the first two questions invariably seem to be: What materials do I buy for soil fertility, and what machinery do I buy to control weeds? This is not the best way to approach organic farm management. An organic farmer cannot merely substitute an organic input directly for a conventional input. When this input substitution approach is adopted, the focus becomes far too narrow and expensive, seeking only replacements for conventional inputs without changing the total approach to farm management. Looking at only one factor in isolation can often result in missing subtle but critical effects, and drawing incorrect conclusions. One must look at a much broader picture, for every factor is interrelated and cannot be isolated from any other factor.

An example of this can be found with the conventional approach to growing alfalfa. To raise yield, large amounts of potassium chloride are commonly applied. Because of the nutritional imbalance this causes, both in the plant and in the soil, the plants become much more susceptible to insects, often requiring insecticide applications. Weed problems will increase.

Klaas and Elizabeth Martens inspect a red kidney bean field, formerly with alfalfa,

Instead of producing high-quality protein, the alfalfa accumulates nitrogenous compounds that are not true proteins or amino acids, as well as potentially toxic nitrates. Animals fed this alfalfa then will frequently have metabolic problems from excessive potassium intake and may suffer from other apparently unrelated health problems due to the nitrates. Few farmers connect the insect, weed, or animal health problems back to potassium fertilization, but will instead try to solve each problem as if it were a separate, isolated condition.

On an "input substitution" organic farm producing alfalfa, the farmer would search the organic standards for organically approved potassium sources, insect repellents, weed control methods, and animal health treatments. This, unfortunately, still does not look at the whole system and does not reveal the true source of the problems.

Ideally, the manager of an organic farm, after a little study, would learn that alfalfa yields can be increased by raising the soil calcium availability and keeping all the other elements in balance. The resulting alfalfa will be higher in soluble solids, making the plants much more resistant to insect attack. Weeds will be suppressed, and soil structure will be improved. The plants will also live longer and will have considerably increased root mass to withstand droughts. When fed to animals, this alfalfa will be a fine source of nutrition and will not contain harmful nitrates, resulting in better animal health and longevity.

For organic production to be successful long-term, the whole philosophy of farm management must be changed. Sustainable agriculture emphasizes that any management decision, practice, crop or input will have effects over multiple years, and the effects will be interconnected to many other factors. Organic farming must be considered a multi-year, whole farm system where no single management decision or individual crop can be viewed separately. Short-term profitability must be balanced with long-term sustainability. For this reason, it is hard to directly compare the economics of conventional and organic farming, using the same criteria. What dollar

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value can be placed on the intentional enhancement of soil microbial activity, organic matter and structure, or on maintaining a soil free of pathogens that may limit choice of future crops? By carefully nurturing these and other critical factors, the productivity and profitability of the farm can be maintained for many years.

CULTURAL WEED CONTROL

Writing in 1939, German agricultural researcher Bernard Rademacher stated that "Cultural weed control should form the basis for all weed control, while the other various means should be regarded as auxiliary only. The necessary condition for any successful weed control is the promotion of growth of the crop species. Vigorous plant stands are the best means for eradicating weeds." The same wisdom must be applied to organic agriculture today.

Heavy reliance on chemicals and powerful machinery in modern agriculture has resulted in farmers who have forgotten how much control they have over the initial weed population in a field. The chemical farming model works in a self-defeating manner. Here, the biological terrain often favors the weeds. Species are specifically selected for their ability to thrive under the particular field and chemical conditions. The weeds that find a niche then successfully reproduce and proliferate, spreading seed for the following season. Each year that the same conditions are provided, such as with the continuous culture of row crops with similar herbicides, those selected weeds will have an enormous advantage.

Cultural weed control seeks to create conditions that cause the crop plants instead to thrive. Any agronomic procedure that encourages healthy soil conditions with a diverse microbial population should also reduce weed pressure. Optimizing the biological terrain of the soil for the crop will create an unfavorable environment for many weeds, effectively reducing weed numbers and vigor. This concept forms the core of effective weed control in an organic production system.

When most people think of non-chemical weed control, they tend to visualize cultivators, rotary hoes and various types of tillage implements. Machinery, just like fertility amendments, are inputs. Before hurrying out to buy the newest advertised machine, it is better to first consider cultural methods as the primary weed control system. It is a great deal easier to prevent weed problems than to kill them. Farmers have a remarkable ability to influence both the vigor and population size of their weed problem before they even turn the first furrow. Failing to utilize cultural weed control measures wisely puts an inordinate degree of pressure on one's mechanical weed control ability and timing.

The production of vigorous crop plants, and therefore effective cultural weed control, encompasses all aspects of organic farm management. This includes maintaining good, balanced soil fertility, planning long-term whole farm crop rotations, wisely choosing crops and crop varieties that are well suited to the farm, using high-quality seed and proper planting techniques, employing sanitation to remove weeds and their seeds from fields, incorporating cover crops wherever possible, and occasionally fallowing problem fields or using cleansing crops where appropriate. Targeting the vulnerable periods in the life cycle of problem weeds may allow a farmer to plan field operations effectively to reduce weed pressure. Coordinating these techniques should prevent the rampant growth of most weeds.

While no single factor can be viewed as a solution to weed control, it is important to examine some of the primary management concepts that contribute to effective cultural weed control.

CROP COMPETITION

Since a vigorously growing crop is less likely to be adversely affected by weed competition, any practice that promotes the health and vigor of the crop plants will reduce weed pressure. It is essential to create conditions where the intended crop can establish dominance quickly. Even in conventional systems, where chemicals are used, crop competition and vigor are really the primary means of effective weed control. That is because many sprays are effective only for a relatively short time before they break down, are diluted by rainfall, or leach out of the weed germination zone altogether. The crop itself must be able to out compete the weeds, otherwise the weeds will rapidly dominate.

Once most row crops "fill the rows," they are big enough to prevent newly emerging weeds from growing, so the crop will remain "clean" until it matures. The goal, then, is to get the crop to this stage as early as possible and to keep weeds from getting established before then. Using high-quality seed, well-calibrated planting equipment, adapted varieties, optimal soil fertility, good soil drainage and tilth, and proper soil preparation will usually result in rapid, vigorous crop growth.

SOIL FERTILITY & CONDITION

In the 1930s, it was noted that heavy use of newly introduced chemical fertilizers in Germany brought about a very perceptible alteration in the proportion of different types of weed species. Some species which had formerly been very common as field weeds were rapidly disappearing, while other types of weeds were becoming much more prominent. We continue to see today that the type of fertility amendments one uses has a powerful effect on weed pressure, in both the number and species present.

In an organic system, it is important to rely on the biological activity of the soil as the main source of fertility and favorable physical structure. An active and diverse microbial population in the soil is key to growing healthy, high-yielding organic crops. While the chemical components of a soil are important, fertility management should focus on feeding the soil microbial life for the long term, rather than tending to the immediate and changing needs of the plants. Any fertility amendments or inputs should be considered supplemental to the natural fertility of the soil. This population can be stimulated by increasing organic matter, by performing certain tillage operations that add oxygen to the soil, and limiting other tillage operations that unnecessarily disturb soil structure, and by avoiding the addition of any materials that will adversely affect microbial growth. The presence of microorganisms and organic material in the soil is essential to holding soil nutrient ions in the crop root zone, to prevent them from being lost to erosion or leaching. Microbial activity in soil may also shorten the life of dormant weed seeds and break down perennial roots and rhizomes, further reducing potential weed pressure.

Soil organic matter, especially material that is actively decomposing, is a tremendous source of plant nutrients and nutrient holding capacity. Well-decomposed organic matter, or humus, and clay parti-

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cles can hold mineral ions in the plant rooting zone, making them available for plant absorption. As dead plants and animals decompose, many of the mineral ions that had once made up their structure are released into the soil solution. Free mineral ions not held securely by electrical attractions to soil particles are rapidly removed by leaching and erosion.

The amount of organic matter in a soil can vary greatly according to soil type and previous cropping practices. In many soils, organic matter can be actively increased to 4 to 5 percent through the use of varied crop rotations, cover crops, and the incorporation of composted manure, leaves or other plant or animal residue. By using a variety of different types of organic materials, the grower encourages a more diverse microbial population than by adding large quantities of a single type of organic matter. Many types of fungi and bacteria actively decompose vegetable matter to produce gummy polysaccharides. These aid in the formation of stable soil aggregates. This type of soil structure aids water infiltration, plant root growth, and microbial growth by creating a soil that is loose and filled with pores containing both water and air.

A field of spelt is interseeded with red clover. The clover is frost seeded into spelt and remains even after the spelt has been harvested, adding valuable organic matter and nutrients to the soil, and shading out weeds.

Soil tests can be very useful, but only if the results are interpreted appropriately for the organic farming production system model. Many soil testing labs, unfortunately, do not provide evaluations that take into account organic farming practices, and therefore they may be of limited value. It is important to select a soil testing lab that will give information on cation exchange capacities, pH, soil organic matter, and percent base saturation for potassium, calcium and magnesium, as well as micronutrient levels.

On soils with a CEC above 8, a 7:1 (percent saturation) calcium-to-magnesium ratio will probably be optimal for weed control and crop plant growth. This ratio, in particular, appears to be a key factor regulating weed population size and strength. When magnesium levels are high relative to calcium levels, high weed populations and soil compaction are more likely to result. The presence of weeds can be a clear indicator of which chemical components are out of balance in the soil. Many prevalent weed species in fields throughout the United States, such as foxtail and summer annual grasses, thrive in hard, compacted soils, most often soils that are also low in calcium and high in magnesium. For this reason, weed control can usually be improved by calcium amendments. However, in a soil that is excessively high in calcium, different weed species will be favored. A correct balance between the two ions is needed.

Not all organically acceptable fertility materials may actually benefit the soil. While most people realize that lime can be a beneficial source of calcium, it is less well known that inexpensive and readily available dolomitic lime, which is high in magnesium, can actually accentuate some weed problems in soils with already adequate or high magnesium. On such soils, substituting gypsum as a lime source may be a better choice. Gypsum, which is calcium sulfate, has the unique ability to supply calcium while slightly lowering the pH of the soil. It also provides needed sulfur. The addition of materials such as lime and gypsum should ideally be made in relatively small amounts over a number of years, allowing them to move evenly through the soil structure without causing a rapid change in a narrow band.

Nutrient ions do not work independently of each other. Deficiencies or excesses of many nutrients may affect the availability of other nutrients. For example, dramatically raising phosphorus levels can induce a zinc deficiency. Micronutrient deficiencies will decrease the vigor of crop plants, making them less competitive and therefore creating more weed pressure. Certain weed species thrive under nutrient-poor or imbalanced nutrient conditions. On a soil that is deficient in zinc and sulfur, weeds like thistle and dandelion tend to develop deep taproots, making them much harder to control with mechanical cultivation. Wild carrot, chicory and dandelion will dominate clover and alfalfa fields that have weakened because of nutrient deficiencies.

When organic fertilizers fail to produce good results, it is often because they are being applied to soils that have a low level of biological activity. A healthy, biologically active soil takes time and deliberate effort to establish, especially if land has been conventionally farmed for many years. During transition, the damage to soil life from chemical fertilizers, pesticides and monoculture persists, making fertility management and weed control more difficult. One way to reduce these problems is to grow as much hay as possible on transitional land. This will help to restore soil biological activity and help reduce weed pressure. It is especially valuable if the hay is fed to animals on the farm, and the manure is returned to the land. However, if the hay is continually sold off the farm, this can rob the soil of essential minerals and cause deficiencies which may then need to be corrected with outside inputs. If a well-managed organic rotation is practiced for several years, the soil microbial popula-

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tion will increase and diversify. This causes soil fertility to improve with minimal need for outside inputs.

One common mistake made by many organic farmers concerns the application of manure or poorly finished compost in an attempt to enhance soil fertility. When improperly or incompletely composted manure is added to a soil, this tends to throw off balance certain soil nutrients and soil microbial systems. This can cause disastrous weed "blooms." This effect is often observed around the perimeter of a manure pile. The effect on the soil is similar to that of many chemical fertilizers. When manure is applied to a field, timing, application rate, and the type of manure should be carefully considered. Anaerobically digested pit manure is especially likely to cause weed problems. If manure of this kind must be used, it is best applied to a growing cover crop in late summer so the nutrients can be assimilated by the cover crop and supplied to successive crops in a higher quality form. Any weeds stimulated by the manure that is applied at this time will be suppressed by the cover crop or will die over the winter.

CROP ROTATION

When the price of organic soybeans is high, it is a temptation to plant as many acres of soybeans as possible. While this may be typical of management on a conventional farm, organic certification and good organic sense usually should discourage this practice. Diverse crop rotations that encompass the entire farm and that are planned a number of years in advance are essential to build a healthy sustainable organic system and to break pest cycles. Continuous monoculture of any species, including well-managed organic grains, effectively selects for populations of weeds, pathogens and insects that are very well adapted to those conditions. Every year that such an environment is created, all adapted pests that escape control measures will reproduce prolifically. In a proper crop rotation, the environment changes each year and will deny pest populations the previous year's favorable conditions.

Bernard Rademacher stated that "If each crop is grown after its most suitable predecessor, the competition of weeds is checked through its vigor alone. Moreover, the danger of plant disease is diminished through suitable cropping, and therewith the formation of poor and patchy stands, which encourage weed growth, is to a large extent eliminated. Finally, good crop rotations promote diverse soil microbial activity that can decrease the vigor of weed seeds." The "rotation effect" has been frequently documented to increase yield and vigor of the crop, therefore making the crop more competitive and reducing weed pressure.

In general, it is best to alternate legumes with grasses, spring planted crops with fall planted crops, row crops with close planted crops, and heavy feeders with light feeders. Careful use of cover crops during times when the ground would be bare adds organic matter and releases nutrients, improves soil microbial diversity, and prevents erosion. A typical long-term rotation on a northeastern United States organic grain farm might start with a small grain underseeded with an alfalfa/grass or clover/grass cover crop. This would be plowed down and planted to corn the next year, and then to soybeans in the third year. The soybeans are followed by a winter small grain, then underseeded to a legume, which may either be kept as hay for two to three years or used as a cover crop.

Organic farmers must experiment with different rotations and learn which will work well on their farm. For a beginning organic farmer, it would probably be best to chart the crops planned for all fields on the farm over the next 3 to 4 years. This will help to plan long-term rotations on individual fields while looking at the overall balance of crops on the entire farm in any given year. It is important to maintain a long-term balance of hay, pasture, row crops, and small grains on the whole farm, taking into account any necessary soil conservation practices, livestock requirements, time constraints, and market profitability.

ALLELOPATHY

One way that plants compete with each other is by releasing chemical substances that inhibit the growth of other plants. This is called "allelopathy" and should be viewed as one of nature's most effective ways that plants deal with competition.

Species of both crops and weeds exhibit this ability. Allelopathic crops include barley, rye, annual ryegrass, buckwheat, oats, sorghum, sudan-sorghum hybrids, alfalfa, wheat, red clover, and sunflower. Vegetables, such as horseradish, carrot and radish, release particularly powerful alleopathic chemicals from their roots.

The alleopathic effect can be used to an advantage when oats are sown with a new planting of alfalfa. Alleopathy from both the alfalfa and the oats will prevent the planting from being choked with weeds in the first year. Buckwheat is also well known for its particularly strong weed suppressive ability. Planting buckwheat on weed problem fields can be an effective cleanup technique. Some farmers allow the buckwheat to grow for only about six weeks before plowing under. This not only suppresses and physically destroys weeds, it also releases phosphorus and conditions the soil.

The alleopathic effect of certain weed species can be detrimental. Alleopathic weeds include quackgrass, giant and yellow foxtail, crabgrass, curly dock and Canada thistle. Studies have shown that giant foxtail can reduce corn yield by 35 percent. Weed alleopathic effects have been shown to reduce soybean yield by as much as 50 percent.

VARIETY SELECTION

Careful selection of crop varieties is essential to limit weeds and pathogen problems and to satisfy market needs. Recent plant breeding in most crops has selected varieties well suited to chemical fertilizer and pesticide management. In small grains, many of these new varieties are short and are not highly competitive. Often, the older, less developed varieties are larger, more disease resistant, and more vigorous than more modern varieties and are able to obtain an optimal yield at lower levels of supplemental fertilizer. Any crop variety that is able to quickly shade the soil between the rows and is able to grow more rapidly than the weeds will have an advantage. It is also important to consider planting disease-resistant varieties if certain pathogens are prevalent in the area.

Plant population needs to be matched to the variety. If a very high population is desired, narrower row spacing is often better than crowding plants tighter within the row. This will also produce faster canopy cover. A very high population of a competitive small grain variety can result in lodging and therefore cause yield loss. Variety selection in soybeans seems largely market driven. It is fortunate that the tofu variety of choice, Vinton 81, is much larger and more vigorous than many commercial soybean varieties that have been bred for modern agronomic conditions. Where shorter soybean varieties are used, it may be necessary to drill a high population

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in order to get sufficient yield, rather than to plant in wider rows. While this approach works for some farmers, it prevents the use of many types of mechanical weed control tools.

SANITATION

It is possible to prevent many new weeds from being introduced onto the farm and to prevent existing weeds from producing large quantities of seed. The use of clean seed, mowing weeds around the edges of fields or after harvest to prevent weeds from going to seed, and thoroughly composting manure before application can greatly reduce the introduction of weed seeds and difficult weed species. It is even possible to selectively hand-eradicate isolated outbreaks of new weeds, effectively avoiding future infestations.

Planting clean, high-quality seed is essential to crop success. Seed that is contaminated with viral or fungal disease pathogens or that has a low germination rate can result in slow or non-uniform plant growth. This will make any mechanical weed control measures more difficult and may permit weeds to dominate the field. When farmers produce their own seed, it pays to have the seed thoroughly cleaned and tested professionally for germination before planting. Legume seed inoculation with the appropriate strain of Rhizobium bacteria will ensure that nitrogen fixation begins quickly and uniformly.

Other sanitation factors to consider would include thorough cleaning of any machinery which might have been used in weedy fields, and the establishment of hedgerows to limit windblown seeds.

DEEP SHADING CROPS

A deep shading crop is one that intercepts most of the sunlight that strikes a field, keeping the ground dark enough to smother any weed seedling soon after emergence. Ideally, such a crop should provide complete shading early in the season and maintain it as late as possible. It is desirable for the crop to be tall and give heavy shade that is high enough to prevent weeds from breaking through the canopy and growing above the crop, which would allow them to mature seeds, as often happens in peas or beans.

Daniel Martens in a field of soy shows the density of plants over the rows, effectively shading out weeds.

Hay crops of alfalfa, clovers, and grasses are particularly good shading crops because any weeds that grow in them will be cut when the hay is harvested and therefore won't be able to make seed. Obviously, if hay fields are allowed to become old and weak before they are rotated back into row crops, weeds will begin to grow in them also. Some farmers find that planting mixtures of legumes and grains, such as "mileage" (soybeans and sorghum) or "peacale" (field peas and triticale) provide much better competition against weeds and improved soil conditioning than their individual components when seeded alone. Other good smother crops include rye, corn, sorghum, barley, canola/rape, and some of the larger varieties of oats and potatoes.

There is some evidence that deep shading may actually hasten the decomposition of weed seeds. It has been widely observed that soil that has been covered with black plastic or other types of mulch is virtually weed free after the mulch is removed. It seems likely that a combination of the shade induced seed dominancy, and the direct destruction of seeds under heavy shade could explain this observation.

SUMMARY

While there are certainly other important factors to consider, these practices illustrate the concept of cultural weed control. Preventing the weeds from getting out of control sometimes seems like an insurmountable task, particularly during the transition period. Once soil is weaned from chemicals and a sustainable, long-term organic system is established, with careful attention to balanced soil fertility and crop rotation, weed pressure usually dramatically decreases, and the weed species change to those that are easier to control.

Many organic farmers could contribute other valuable cultural weed control practices. The authors, Mary-Howell & Klaas Martens, would like to hear from other organic farmers who have additional ideas on cultural weed control to share. They can be reached at <kandmhfarm@sprintmail.com>.

PRINCIPLES OF SUSTAINABLE WEED MANAGEMENT FOR CROPLANDS

AGRONOMY SYSTEMS SERIES

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.*

By Preston Sullivan
NCAT Agriculture Specialist
September 2003

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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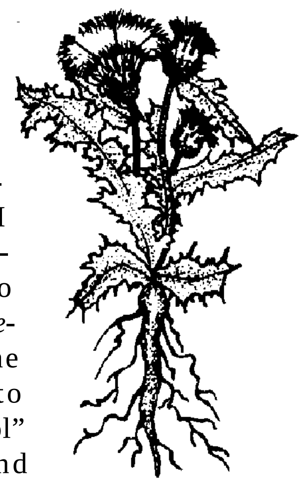


The "weed control" paradigm is *reactive*—it addresses weed problems by using various tools and technologies. "How am I gonna *get rid of* this velvet-leaf?" and "How do I *control* foxtail?" are *reactive* statements. The conventional tools to "get rid of" or "control" weeds—cultivation and herbicides—are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

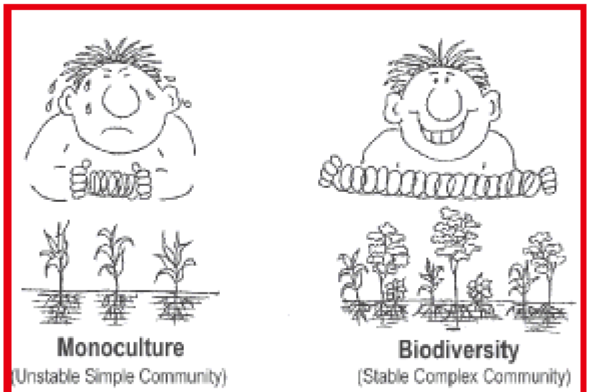


Figure 1.
Monoculture vs. Biodiversity (2).

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 Broadleaf weeds	No Herbicide Broadleaf weeds	Herbicide Grass weeds	No Herbicide 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 *percent control*	Grass weeds *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

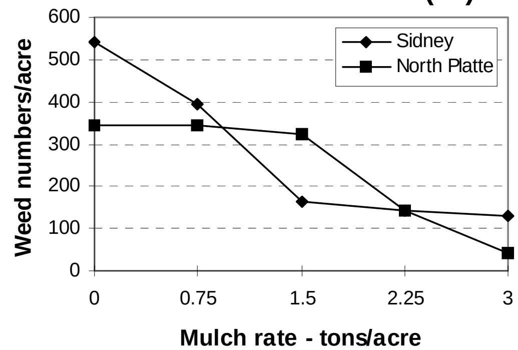
In general, typical levels of cover crop residues, when left on the soil surface, can be expected to reduce weed emergence by 75 to 90% (15). As these residues decompose, the weed suppression effect will decline also. Residues that are more layered and more compressed will be more suppressive (15). Small-seeded 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.

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.

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.

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:

Extension Communications
Attention: Lisa Scarborough
3614 ASB, Room 1712
Iowa State University
Ames, IA 50011
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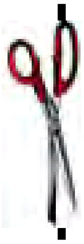

1. Does this publication provide the information you were looking for? How could it be improved?

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

3. Do you know of any related research that would add to the information presented here?

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

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Organic Weed Management

By: Mike Burton, Assistant Professor, Crop Science, NCSU; Randy Weisz, Crop Science Extension Specialist, NCSU; Alan York, Crop Science Extension Specialist, NCSU; Molly Hamilton, Crop Science Extension Assistant, NCSU

Weed pest management must be an ongoing consideration for organic producers in order to produce acceptable yields and crop quality. Using a system of weed management that includes multiple tactics can help to reduce losses that weeds cause in the short and long term. Here we have divided various tactics into two major categories, cultural and mechanical. Typically, cultural tactics are associated with enhancing crop growth or cover and mechanical tactics are some form of physical manipulation that is directed to kill, injure or bury weeds.

Cultural Tactics

Crop Rotation: It is beneficial to have a rotation system that includes crops with different life cycles, growth patterns and management techniques in order to reduce the chance that weeds can proliferate over successive years. For example, a rotation could include a summer crop, winter crop, legume, grass, a cultivated crop (corn) and a non-cultivated crop (wheat or hay). Because some weeds are triggered to germinate by tillage, rotations of tilled and no-tillage systems (e.g. a forage or hay crop) may also be of benefit.

Cultivar and Cover Crop Selection: Competitive differences exist among crop cultivars. Tall cultivars and cultivars with rapid establishment, quick canopy closure, high leaf area index and yield stability are reportedly more competitive with weeds than short or dwarf cultivars, or cultivars (or seedlots) that are of low seed vigor, are slow growing, or have low leaf area index. Some weed species are suppressed by the exudation of crop-produced allelochemicals (naturally produced compounds that can affect the growth of neighboring organisms) in standing crops or in residues of allelopathic crops (e.g. rye cover crop). Results of studies conducted on wheat (Wu et al. 2000, 2001) and rye (Reberg-Horton 2002) have demonstrated that the production of allelochemicals varies widely with cultivar and can change during crop development. Efforts to enhance allelopathic characteristics of cultivars have begun in the small grains breeding program at NC State University and elsewhere.

Seed Quality: Seed cleanliness, percent germination and vigor are characteristics that can influence the competitive ability of the seedling crop. Planting un-clean (especially farmer-saved) seed which is often of lower quality than certified seed and may contain unknown quantities of weed seed or disease, may result in the introduction of pests not previously observed on the farm. There is also a risk of increasing weed density and moving weeds to parts of fields that were not previously infested. Percent germination and vigor are important to weed management because they collectively affect stand quality and time to canopy closure.

Planting – Sowing Date and Seeding Rate: Sowing date and seeding rate affect the crop population, which must be optimal in order to compete with weeds. Carefully maintained and adjusted planting equipment will insure that the crop seed is planted at the correct depth and is planted uniformly for uniform emergence.

Cover Crops: Cover crops can provide benefits of reduced soil erosion, increased soil nitrogen, and weed suppression through allelopathy, light interception, and the physical barrier of plant residues. Cover crops such as rye, triticale, soybean, cowpea, or clover can be tilled in as a green manure, allowed to winter kill, or be killed or suppressed by undercutting with cultivator sweeps, mowing, or rolling. Warm-season cover crops help to suppress weeds by establishing quickly and out -competing weeds for resources. It is important to carefully manage cover crops so that they do not set seed in the field and become weed problems themselves.

Fertility – Compost and Manures: Uncomposted or poorly composted materials and manures can be a major avenue for the introduction of weed seed content. However, soil fertility that promotes crop growth helps to reduce the chance that weeds will establish a foothold in an area of poor productivity, i.e. poor (noncompetitive) crop performance leaves the door open to pests (disease, insects and weeds).

Sanitation and Field Selection: Weeds are often spread from field to field on tillage, cultivation or mowing equipment. Cleaning equipment before moving from one field to another, or even after going through a particularly weedy section (or problematic weed patch), can prevent weeds from spreading between fields or within fields. When transitioning to organic, it may be a good idea to start with fields that are known to have low weed infestations. Fields with problem weeds, such as Italian ryegrass, wild garlic, johnsongrass or bermudagrass, should be avoided if possible, when first transitioning to organic management as these fields will be more difficult to manage when first practicing organic weed control.

Critical Period of Weed Interference: A critical period of weed interference is the time in a crop's life when weed competition can adversely affect yield. Critical periods of weed interference will vary by crop, weed species and growing conditions. This concept does not apply to organic small grains because there are very few weed removal options once the crop is established. However, for soybeans a conservative critical period is roughly 2.5 weeks after planting to about 5 weeks after planting, and for corn between 3 weeks after planting and 6 weeks after planting. This is the period when weed competition will adversely affect the crop and weeds, therefore, need to be controlled. Some early competition (before 2.5 or 3 weeks after planting) can be tolerated, assuming you can remove the weeds later. This can be difficult with organic management as the weeds will be too large to effectively cultivate out, therefore the goal should be consistent weed control up to 4 or 5 weeks for soybeans and 6 weeks for corn after planting. After the crop reaches the end of this critical weed interference period, later-emerging weeds may look ugly in the field but they do not affect yield.

Mechanical Tactics

A healthy, vigorous crop is one of the best means of suppressing weeds. However, some physical tactics are discussed below that can be used in conjunction with good cultural practices to kill or suppress weeds – leaving the advantage to the crop. The goals of mechanical weed control are to eliminate the bulk of the weed population before it competes with the crop and to reduce the weed seed bank in the field. Important factors to think about for mechanical weed control are: weed species present and size, soil condition, available equipment, crop species and size, and the weather. Since it might not be necessary to use a tactic on the entire field, knowledge of weed distribution and severity can be valuable. Obviously, farmers will want to minimize tillage and cultivation to reduce environmental costs (e.g. erosion, destruction of soil structure, or loss of soil organic matter) and operating costs (e.g. fuel and equipment)—and these goals must be balanced with weed management. Tillage, blind cultivation, and between-row cultivation are important aspects of mechanical weed control.

Tillage: Proper field tillage is important to creating a good seedbed for uniform crop establishment—often a critical part of a crop's ability to compete with weeds. Tillage should also kill weeds that have already emerged. In the spring, when the soil is warm, weeds often germinate in a flush after tillage. A moldboard plow will bury the weed seeds on the surface (those that were being cued to come out of dormancy by warming soil) and bring up dormant weed seeds from deeper in the soil. These weed seeds will normally be slower to come out of dormancy than weed seeds previously on the surface. Chisel plowing or disking does not invert the soil and can result in an early flush of weeds that will compete with the crop (Martens and Martens 2002). The **stale seedbed technique** can be used, if there is enough time before planting, as an alternate approach. In this technique, soil is tilled early (i.e. a seedbed is prepared), encouraging weed flushes, and then shallow tillage (or flaming) is used again to kill the emerged or emerging weed seedlings. While this technique should not be used in erodible soils, it can be used to eliminate the first flush or flushes of weeds that would compete with the crop.

Blind cultivation: Blind cultivation is the shallow tillage of the entire field after the crop has been seeded. Generally, it is used without regard for the row positions. It is the best opportunity to destroy weeds that would otherwise be growing within the rows and would not likely be removed by subsequent mechanical tactics

(Martens and Martens 2002). Blind cultivation stirs above the level of seed placement (further emphasizing the need for accurate crop seed placement), causing

the desiccation and death of tiny germinating weed seedlings. Crop seeds germinating below the level of cultivation should suffer little, if any, injury. The first blind cultivation pass is usually performed immediately before the crop emerges, and a second pass is performed about a week later (Martens and Martens 2002). This depends, of course, on weather, soil and crop conditions and weed pressure. Blind cultivation is most effective when the soil is fairly dry and the weather is warm and sunny to allow for effective weed desiccation. Blind cultivation equipment includes rotary hoes, tine weeders, spike tooth harrows, springtooth harrows and chain link harrows (Martens and Martens 2002).

Between-row cultivation: Between-row cultivation should not be the primary mechanical weed control, but should be used as a follow-up tactic to control weeds that escaped previous efforts. Between-row cultivation should be implemented when weeds are about one inch tall and the crop is large enough to not be covered up by dirt thrown during the cultivation pass. Usually more than one cultivation pass is needed. It may be useful to reverse the direction of the second (and alternate) cultivation pass in order to increase the possibility of removing weeds that were missed by the first cultivation. Planting corn in furrows can allow more soil to be moved on top of weeds and may be a useful practice on some farms. All cultivation passes should be done before the canopy closes or shades the area between the rows. After this time, the need for cultivation should decrease, as shading from the crop canopy will reduce weed seed germination, and equipment operations can severely damage crop plants. Cultivating works best when the ground is fairly dry and the soil is in good physical condition (Martens and Martens 2002). There are many types of cultivator teeth, shanks and points. Choose the cultivating equipment that works best in your soils. Points for cultivator teeth vary in type and width. Half sweeps (next to the row) and full sweeps (between rows) are probably the most versatile and common, but each type of point works best under certain conditions and on certain weed species (Martens and Martens 2002). Using fenders on cultivators at the first pass can keep the soil from covering up the crop. Cultivator adjustments are very important and should be made to fit the field conditions. Tractor speed should also be modified through the field to compensate for variability in soil type and moisture.

There are also other methods of mechanical weed control that may be effective and efficient, depending on the equipment, budget, and goals of the farm.

Flame weeding: Flame weeding provides fairly effective weed control on many emerged broadleaf species and can be used in tilled or no-tillage fields. Grasses are often not well controlled by flaming (growing points are often below the soil surface). Flame weeding should only be performed when field moisture levels are high and when the crop is small.

Hand weeding and Topping: Walking fields and performing hand weeding or topping weeds (cutting off the tops) can vastly increase familiarity with the condition of the crop and distribution of weeds or other pests. Farmers who are familiar with problem locations can remove patches of prolific weeds before they produce viable seeds and reduce problems caused by weeds that escaped management in the long run. Topping weeds can reduce seed set and, therefore, the weed seed bank in the field.

No-till organic weed control. There is growing interest in organic no-till production. Advantages such as reduced cultivation, reduced soil erosion and organic matter additions have made no-till organic an attractive idea. Recently, research has been done on no-till organic agriculture in many parts of the country, and there is potential for some organic systems to be much less reliant upon mechanical weed control. The basic premise for no-till organic weed control is to plant a cover crop that will produce a high biomass, then mow or roll that cover crop and no-till plant into the residue. This system, however, takes a lot of planning to work well. Weed control may be a challenge if the cover crop residue is not able to smother germinating weeds effectively. In North Carolina, tillage is an important technique for controlling insect pests such as Hessian fly, wireworms and cutworms in organic wheat and corn production. These insect pests may become problems in organic no-till systems. The following articles and sites provide more information about organic no-till, especially the New Farm site:

The New Farm®
The Rodale Institute

Herbicides. There are a few organically approved herbicides that can be used in organic production. These include acetic acid (distilled vinegar) on its own or in combination with citric acid, products that contain clove oil, soap-based herbicides (non-detergent), some corn gluten meal products, and hot or boiling water. These herbicides are reported to work best on young weeds. Organically approved products can be found on the OMRI website. While these products do have potential for controlling some weed pests, no research has been done on them in North Carolina and, therefore, we can give no recommendations for their use in the state. The cost of these organically approved herbicides may be prohibitively expensive for field crop production.

References:

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Wu, H., J. Pratley, D. Lemerle, and T. Haig. 2001. Allelopathy in wheat (*Triticum aestivum*).
Ann. Appl. Bot.139: 1-9.

Wu, H., J. Pratley, D. Lemerle, and T. Haig. 2000. Evaluation of seedling allelopathy in 453 wheat (*Triticum aestivum*) accessions against annual ryegrass (*Lolium rigidum*) by the equal-compartment-agar method. Aust. J. Agric. Res. 51:937-944.

Several weed identification guides are available for purchase through various publishers, and NCSU Ag Communications offers an excellent and inexpensive resource entitled *Identifying Seedling and Mature Weeds* that was developed for the Southeastern USA. However, it does not include some troublesome weed species in NC grain crop production. Another recommended guide is *Weeds of the Northeast*. Contact information for each publisher is listed at the end of this document. A few Internet guides are also available; their URLs at the time of printing were:

http://www.ppws.vt.edu/weedindex.htm
http://web.aces.uiuc.edu/weedid/
http://www.weeds.iastate.edu/weed-ad/weedid.htm

Weed Identification Guides
Identifying Seedling and Mature Weeds (AG-208)
North Carolina Agricultural Research Service and Cooperative Extension Service
Publications Office
Box 7603, NCSU, Raleigh, NC 27695-7603
$10

Weeds of the Northeast
Uva, Neal and DiTomaso (1997)
Cornell University Press
P. O. Box 6525, Ithaca, NY 14851-6525
607-277-2211

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Weed Management in Organic Cropping Systems

When managing weeds in organic systems, producers use many of the same techniques used in conventional systems, but they rely much more on nonchemical control strategies. The primary weed control strategies for organic systems are cultural and mechanical, focusing on prevention, crop rotation, crop competition, and cultivation.

To plan an effective weed management program in organic systems, you should consider historical pest problems, soil management, crop rotation, machinery, markets, weather, and time and labor. Adjusting weed control strategies based on these factors and observing and avoiding potential threats will help you stay ahead of weed problems.

Key Points

- Understand weed biology.
- Rotate crops and alter planting dates to disrupt weed life cycles.
- Encourage competitive crop production with sound agronomic practices.
- Use mulches and cover crops to help suppress weeds.
- Timely tillage and cultivation is critical for weed control.
- Chemical weed control is generally not allowed in organic production systems.

PREVENTION

Prevention focuses on keeping new weeds out and preventing the further spread of weed seed or perennial plant parts. Stopping the addition or introduction of weed seed to the soil can be particularly critical for successful weed management.

Understanding weed biology is an important component in developing a preventive approach. Weed species have strengths and weaknesses that make them vulnerable or resilient at different stages in their life cycle. Therefore, proper identification and knowledge of weed life cycle and reproduction and spread are important factors for developing management strategies. For example, disking or field cultivating a creeping perennial such as quackgrass or hedge bindweed in the spring may make the problem worse by spreading underground rhizomes or other vegetative structures.

Some preventive tactics can be classified as *sanitation*: removing or destroying weeds in fields or near fields before they flower and release weed seed. Weed seeds can live for a number of years, depending on the species and whether the seed is exposed or buried beneath the soil surface. If necessary, weeds may need to be removed from the field by hand before they produce seed. Weeds can also be introduced into fields through manure, compost, hay, straw, animal feed, contaminated crop seed, or other materials. Whenever you plant, apply, or drive something in a field, make an effort to learn whether weed seeds are present and weigh the benefits against potential risks.

CULTURAL WEED CONTROL

Any tactic that makes the crop more competitive against weeds is considered cultural management. Some cultural practices—in particular, crop rotation and altering planting dates—can be critical components of weed management in organic production systems.

Organic growers should plan rotations so that weed species favored in one year or season will not be favored in another year or cropping sequence. This generally means mixing summer annual crops with fall-seeded species or even perennials that allow different weed management strategies.

The planting date will influence the type and number of weeds present. Delaying planting of spring-seeded crops is common among organic producers. This planting delay may sacrifice some yield potential, but higher soil temperatures will help the crop emerge more quickly and weeds that emerge earlier in the season can be killed before planting the crop to reduce the potential weed seedbank.

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A *stale seedbed* is a technique sometimes used in vegetable production systems that can also be used in agronomic crops. In this technique, a seedbed is tilled several weeks before planting. The weeds are allowed to emerge and then they are killed, while still small, by shallow cultivation, flame weeding, or other nonselective methods. Depending on the length of time before planting, one or more flushes of weeds may emerge and be killed between seedbed preparation and planting. The success of a stale seedbed depends on the weed spectrum and the time of planting. Delayed or later-planted crops are generally more successful. Late-emerging weeds will still be a potential problem.

Crop competition is another important component of cultural weed control and an effective way to control weed growth. Tactics that allow the crop to establish quickly and dominate will help reduce the impact of weeds. Use high-quality, vigorous seed, adapted varieties, uniform proper placement of the crop seed, optimal soil fertility, and plant populations that lead to vigorous crop growth and canopy closure. A vigorous growing crop is less likely to be adversely affected by weeds.

MULCHES AND COVER CROPS

Because soil open to sunlight helps weeds grow and complete, mulches are used to help manage weeds in some organic production systems. The mulch provides a physical barrier on the soil surface and must block nearly all light reaching the surface so that the weeds which emerge beneath the mulch do not have sufficient light to survive. Plastic mulches are acceptable in some organic programs, but are generally not practical for lower-valued, large-scale field crops. Mulches of organic material, such as straw, newspaper, or killed cover crop residue left on the surface, can also effectively block sunlight and are more commonly used in organic row crop production systems.

Cover cropping can help manage weeds in several ways. Cover crops can provide an opportunity for crop rotation and rapid turnover of weed seedbanks. In addition, cover crops can provide some weed control by competing with weeds for light, moisture, nutrients, and space. This can be particularly helpful for suppressing winter annual weed growth or certain cool-season perennials. cover crops and their residues also can act as mulches or physical barriers by smothering weeds, suppressing weed seed germination and growth, and lowering soil temperatures. In general, the larger the cover crop and greater the biomass or dry matter production, the greater the impact on weeds. Cover crops also may contain allelopathic compounds, which are released from living or decaying plant tissue, that chemically interfere with weed growth. However, these qualities can vary depending on the type and quantity of cover crop and environmental conditions during the growing season. Despite these potential benefits, physical and chemical effects from cover crops may not provide adequate weed control. Use mechanical control tactics and cultural controls to complement cover crops for weed management.

MECHANICAL WEED CONTROL

Mechanical weed control is critical for managing weeds in organic systems. In organic row crops, such as corn or soybeans, mechanical cultivation is generally necessary for adequate weed control. Mechanical weed control includes the use of preplant tillage such as plowing, disking, and field cultivating. These types of primary and secondary tillage can help reduce the rate and spread of certain perennial weeds and can also kill emerged weed seedlings and bury weed seeds below the germination zone.

Most organic corn and soybean producers prepare a conventionally tilled seedbed before planting their spring crop. Cultivation should generally begin a few days after planting. To control very small weed seedlings that are just beneath the soil surface or barely emerged, implements such as a rotary hoe, chain-link harrow, or tine weeder are dragged over the field. These implements will displace small seedling weeds and expose them to the drying effects of the wind and sun.

Rotary hoes, tine weeders, or similar implements are the best method for controlling weeds in the crop row. Operate a rotary hoe at 10 to 12 miles per hour with enough drag to stir the soil and displace the small seedlings. Continue to use a rotary hoe or similar implement about every 5 to 7 days as long as the weeds are germinating or until the crop is too big. Do not rotary hoe soybeans in the "hook" stage (when the stem is exposed and the cotyledons have not yet opened above the ground). Also, use rotary hoes or similar implements in the afternoon, when turgor pressure is less and soybeans and corn are more flexible. In general, up to three rotary hoeings may be performed within 2 to 3 weeks after planting.

Crop rows planted 30 inches or more apart allow for row cultivation. Once soybeans have two to three trifoliate leaves and corn is beyond the two-leaf stage (V2) and 8 to 10 inches tall, use a row cultivator to control small weed seedlings. Shallow cultivation at 1 to 2 inches deep will avoid harming crop roots. Continue to cultivate at 7- to 10-day intervals until the corn is too tall and the soybean canopy closes the rows. Organic corn and soybeans generally require one to three cultivations depending on weed species, severity, and rainfall. Cultivation works best when performed during the heat of the day in bright sunlight; weeds quickly desiccate and die under these conditions. Rainfall shortly after cultivation or wet cloddy soils at or following cultivation may allow weeds to recover and survive. Hand-pulling escaped weeds will help ensure maximum crop yield and prevent weed seed production, which can affect future weed problems.

Mowing may also play a critical role in managing weeds in forage crops or noncrop areas. Repeated mowing reduces weed competitive ability, depletes carbohydrate reserves in the roots, and prevents seed production. Some weeds, mowed when they are young, are readily consumed by livestock. Mowing can kill or suppress annual and biennial weeds. Mowing can also suppress perennials and help restrict their spread. A single mowing will not satisfactorily control most weeds; however, mowing three or four times per year over several years can greatly reduce and occasionally eliminate certain weeds, including Canada thistle. Also, mow along fences and borders to help prevent the introduction of new weed seeds. Regular mowing helps prevent weeds from establishing, spreading, and competing with desirable forage crops.

HERBICIDES

Chemical weed control is generally not allowed in organic crop production systems. The USDA National Organic Program (NOP) rule does allow certain nonsynthetic soap-based herbicides for use in farmstead maintenance (roadways, ditches, right-of-ways, building perimeters) and in ornamental crops. In addition, several products that contain natural or nonsynthetic ingredients are classified as Allowed or Regulated by the Organic Materials Review Institute (OMRI). Regulated substances are listed with a restriction on the USDA National List or in the NOP rule. The OMRI listing does not imply product approval by any federal or state government agency. It is the user's responsibility to determine the compliance of a particular product.

Corn gluten meal is sold as a preemergence herbicide in some production systems. However, because of the volume of product necessary and the associated cost, corn gluten meal is generally not practical for agronomic crop production systems. In addition, the need for and use of corn gluten for weed control must be explained in the Organic System Plan and it must not be derived from genetically engineered sources. To learn more about corn gluten, visit the corn gluten meal research Web page at Iowa State University (www.gluten.iastate.edu).

The nonsynthetic postemergence herbicides contain plant-based ingredients, including eugenol (clove oil), garlic, and citric acid, and act as nonselective contact-type herbicides. They will injure or kill all vegetation they come in contact with. The need for the use of herbicides derived from plant or animal sources should be explained in your Organic System Plan, and you must obtain permission from your organic certifying agencies to use these materials. Acetic acid or vinegar is an ingredient in a number of products, but we believe it is not currently approved as an herbicide for organic crop production systems. Additional products and ingredients are currently under review.

Nonsynthetic adjuvants (such as surfactants and wetting agents) are allowed unless explicitly prohibited. All synthetic adjuvants are prohibited, which includes most adjuvant products on the market. However, a number of plant-based adjuvants are available. These are often derivatives of pine resin (Nu-Film P), yucca (Natural Wet), or other plant-based substances. Some products contain acidifying agents and other ingredients touted to enhance pesticide or nutrient uptake. Check with your organic certifier to find out if these additives are allowed.

The following table contains some herbicides listed by OMRI at the time of printing. Some of these products already include surfactant-type adjuvants in their formulation. Penn State does not assure the effectiveness or allowance of any of these products.

Table 1. Herbicides listed by the Organic Materials Review Institute (OMRI) for use in organic production as of May 2004. All products listed are classified as Regulated.

Product	Active ingredients	Manufacturer
Alldown	Citric acid plus garlic plus acetic acid	Summerset Products www.sumrset.com 952-820-0363
Corn gluten meal	Corn gluten meal	Numerous—for more information see. www.iastate.edu/~isurf/tech/cgmwebsite.html
Ground force	Citric acid plus garlic plus acetic acid	Abby Laboratories www.abbylabs.com
Herbicidal soap	Various salts of fatty acids	Several brands—may be synthetic and used for nonfood crops only
Matran II	Clove oil	EcoSmart Technologies, Inc. www.ecoipm.com 888-326-7233
Xpress	Thyme and clove oil	Bio HumaNetics www.biohumanetics.com 800-961-1220

Prepared by William Curran, professor of weed science.

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Integrated Pest Management Concepts for Weeds in Organic Farming Systems

Last Updated: March 23, 2010

eOrganic author: Mark Schonbeck, Virginia Association for Biological Farming

Source: Schonbeck, M. 2007. Beating the weeds with low-cost cover crops, intercropping and steel. The Virginia Biological Farmer 30:7-8. Available online at: http://www.vabf.org/vbf2nd2007.php.

Introduction

Integrated Pest Management (IPM) aims to protect agricultural crops from economic damage by insect pests, weeds, plant pathogens, and other harmful organisms, while reducing reliance on hazardous pesticides. The term *integrated* means the practitioner implements a coordinated pest management strategy utilizing multiple tools and practices that are compatible with one another and with the health and stability of the farm as a living system. The most effective IPM programs are based on an ecological understanding of the pests' interactions with the crops, other organisms, and the environment (Dufour, 2001).

Since the advent of synthetic pesticides in the mid-20th century, conventional pest management has consisted of spraying whenever pests appear, or even on a "calendar schedule" based on a worst case scenario for the target pests. Herbicides are routinely applied pre- and postplant, based on the major weed species, emergence patterns, and expected competition against the crop in a given region or locale.

During the 1970s, heavy pesticide use on the nation's farmlands raised human health and environmental concerns, as well as increasing pest resistance to the chemicals. In response, agricultural scientists explored ways to control pests more effectively with fewer pesticide sprays. Practical on-farm applications of these endeavors became Integrated Pest Management, or IPM.

Early students of IPM sought to understand both crop and pest within the larger context of the *farm ecosystem* or *agroecosystem*—consisting of all the living organisms on the farm and its immediate surroundings, and the interactions among those life forms and their physical environment. The agroecosystem includes the farm's crops, weeds and natural vegetation; livestock, wildlife, insect and other pests, and their natural enemies; soils and their tremendous diversity of micro- and macroorganisms; ground and surface waters, topography, and climate. Understanding these interactions and how they can impact the crop and its pests can point the way to nontoxic and non-disruptive practices that limit pest species' ability to proliferate and become a problem that requires a pesticide treatment. Early IPM programs emphasized cropping system planning based on this knowledge, and preventive measures, as well as a "spray only when really necessary" approach to pest occurrences (Dufour, 2001). Several principles guided these efforts:

- Restore and maintain natural balance within the farm ecosystem, rather than attempt to eliminate species. Higher biodiversity usually confers greater stability.
- Monitor pest and beneficial populations; take steps to protect and enhance natural pest controls.
- The mere presence of a pest does not automatically mandate a pesticide application. Appropriate decision making criteria, such as Economic Thresholds (ETs) are applied to determine whether and when control measures are warranted (Fig. 1).
- All pest control options—physical, cultural, and biological, as well as chemical—are considered before action is taken.
- Integrate a set of complementary techniques and tools that work additively or synergistically, taking care that one tactic does not interfere with another.

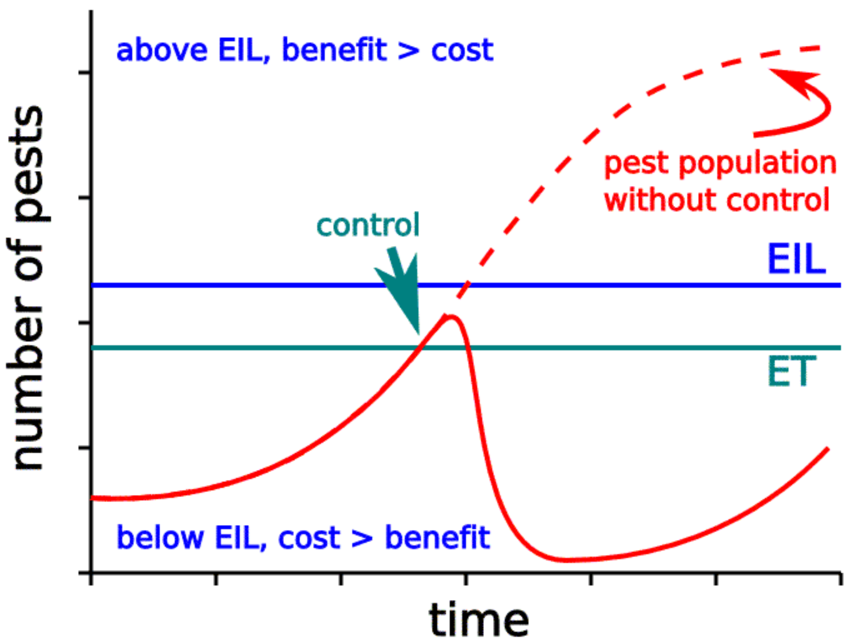

Figure 1. In Integrated Pest Management, the Economic Injury Level (EIL) is defined as that pest population level at which the dollar cost of crop yield loss to the pest begins to exceed the dollar cost of the recommended control measures for the pest. The Economic Threshold (ET) is that level of pest population at which the pest, if left untreated, is likely to reach or exceed the EIL. Therefore, the ET is almost always lower than the EIL, and is considered the point at which the farmer should take action against the pest. Therefore, the ET is sometimes called an Action Threshold (AT). Figure credit: Ed Zaborski, University of Illinois.

Biointensive IPM

In practice, IPM has evolved into the science of using field scouting protocols and research-based economic thresholds to determine whether and when to use a pesticide. When pest population or visible pest damage reaches a level at which economically significant losses of crop yield or quality are likely in the absence of control measures, a pesticide is applied. While this "conventional IPM" approach can significantly reduce pesticide use, it still relies on chemicals as the primary tool in pest management. Pest- and disease-resistant crop varieties are sometimes recommended; otherwise the proactive, integrated and ecological aspects of IPM are often neglected. In the words of agroecologist Miguel Altieri, "Integrated Pest Management should be oriented to preventing outbreaks by improving stability of the crop systems, rather than coping with pest problems as they arise." (Altieri, 1995, p. 268).

The limited vision of conventional IPM has led sustainable agriculture researchers to take the next step into biologically-based IPM, or biointensive IPM (Dufour, 2001), which returns to the ecological roots of the original IPM concept. Biointensive IPM:

- Emphasizes proactive (preventive) strategies, adopted in planning the cropping system, to minimize opportunities for pests to become a problem
- Utilizes living organisms, ecosystem processes and cultural practices to prevent and manage pests whenever practical
- Employs the least toxic materials and least ecologically-disruptive tactics when reactive (control) measures are needed to deal with an outbreak

Note that the USDA National Organic Program (NOP) **requires** certified organic growers to take this approach to pest management and to document both preventive and control measures and their rationale. Some cultural practices that have been validated through extensive research, and that more and more farmers are adopting as part of their IPM programs, include:

- Designing more diverse and optimally functioning crop rotations that reduce habitat for major pests and increase habitat for their natural enemies
- Farmscaping—border plantings of diverse flowering plants that provide habitat for predators and parasites of pests
- Maintaining healthy, biologically active soils (belowground biodiversity)
- Planting locally adapted, pest resistant crop cultivars
- Optimizing nutrients, moisture, planting dates, and patterns for crop vigor

The biointensive IPM practitioner is both a perpetual student and a “doctor” of the entire farm ecosystem, not just the crop or its immediate pests. Because of the great complexity and constantly changing nature of ecosystems, the farmer must continually observe populations and interactions, and the results of preventive and control measures taken. Good records help in the ongoing process of adapting and fine-tuning the biointensive management system. Finally, biointensive IPM is inherently *site specific* in that it must be adapted to each farm based on its soil types, climate, crop and livestock mix, other organisms (pests, weeds, beneficials, native vegetation, wildlife, etc.), available equipment and resources, and business/marketing plan.

Integrated Weed Management

Historically, IPM has focused largely on insect pests, and IPM programs have been developed for the major insect pests of many crops. However, increasing evidence of health and environmental risks related to herbicides, rising input costs, and problems with weed resistance have stimulated increased interest in developing Integrated Weed Management (IWM) programs (see sidebar).

Sidebar:
Recognizing the Need for Integrated Weed Management (IWM)

In a recent article in *Weed Science*, Swanton et al. (2008) advocate implementation of knowledge-based IWM to reduce herbicide use and thus slow the development of herbicide resistance by major weeds. They cite four vital areas of knowledge:

- The effects of different tillage practices on weed and weed seed populations
- Time of weed emergence relative to the crop
- The critical period for weed control, when weed competition can reduce crop yield

- The “harvest window,” when later-emerging weeds can no longer significantly affect yield of the current crop.

The *critical period for weed control*, is that portion of the crop's lifecycle when "it is essential to maintain a weed-free environment to prevent yield loss." This has been estimated as extending from the 3-leaf stage until about the 10- to 14-leaf stage for corn, and from the first to the third trifoliolate leaf stages for soybean. For vegetable crops, a "minimum weed-free period"—from planting until the end of the critical period—is sometimes estimated as the first third to first half of the crop's life cycle.

The *harvest window* is simply defined as the time from the end of the critical period of weed control until crop harvest. The authors posit that weeds emerging during the harvest window do not warrant control treatments unless they affect quality or marketability of the crop, noting that “good weed management should be judged on decisions made early in the development of the crop, not on appearances at harvest.” However, since late-emerging and post-harvest weeds can still form seed, organic growers especially must manage them to prevent large additions to the soil's weed seed bank.

The authors address barriers to adoption of IWM, including farmer perception of higher risk, insufficient research verifying reduced costs and risks under good IWM, and lack of government and industry support for this approach. They recommend research and development of decision support systems that base herbicide recommendations on “weed density thresholds” and relative developmental stages of weed and crop. For organic growers, they cite “a need for weed management decision support tools for mechanical control practices.”

Although Swanton et al.'s 2008 article was written mainly from a “non-organic” viewpoint that still includes herbicides as a major weed management tool, it may offer valuable insights for newly-converting organic growers worried about fuel costs or the soil quality impacts of replacing these chemicals with tillage and cultivation. One caution for organic growers is that the use of weed density thresholds as recommended by Swanton et al. (2008) could result in large deposits into the weed seed bank from uncontrolled “harvest window” weeds. However, the knowledge-based approach can help organic producers optimize cultivation practices and timing to get the best results at the least cost.

Many of the IPM principles discussed earlier apply directly to weeds, while some require modification, particularly for organic weed management. Insect IPM programs are based to a large degree on economic thresholds (ETs), and often on the use of specific biological controls against target pests. However, the dynamics of weed pressure differ significantly from those of insect pests or diseases in several ways.

- Because of the nature of annual cropping systems, weeds reliably occur every year; thus, farmers need to plan appropriate reactive (control) measures as well as proactive cultural practices for each crop.
- While most insect or disease problems entail one or two harmful organisms for which specific biocontrols are often either naturally present or commercially available, weed problems usually result from the combined effects of several or many weed species (Fig. 2).
- Economic thresholds are less useful in IWM than in insect IPM because weed density thresholds vary widely among the many possible weed–crop pairs. Thresholds become even more difficult to quantify when several weed species occur together and exert multiple effects on the crop (Fig. 2).
- Because any weed reproduction can create greater weed problems for subsequent crops in the same field, the IWM practitioner needs to take a multiyear perspective, asking not only, "Will this weed hurt this crop?" but also, "Will this weed's progeny hurt future crops?" (Fig. 3). Although insect pests also leave progeny, most are sufficiently host-specific that rotating to a nonhost crop can effectively limit pest population increases.

Figure 2. With many different weed species growing with this sweet corn, it becomes virtually impossible to define an economic threshold in numbers of weeds per square yard at which crop yield begins to decline significantly. In this case, weed control is urgently needed to save the corn crop. However, a specific biocontrol that takes out one of the weed species present might have little impact on total weed pressure, while a generalist natural enemy would likely attack the crop as well as the weeds. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Figure 3. The large pigweeds in this field emerged late enough not to have much impact on the pumpkins and winter squash, which have yielded well. However, each weed is about to shed thousands of viable seeds,

and could create a much worse weed problem next year unless they are removed from the field promptly. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Within the context of the current season's crop, IWM aims to keep the crop ahead of the weeds, and thereby tip the competitive balance in favor of the crop (Sullivan, 2003). This is done by strengthening the crop through best cultural practices (varieties, planting dates and patterns, nutrients, water, etc.—sometimes called Integrated Crop Management or ICM), as well as by weakening the weeds through proactive and reactive tactics.

In insect IPM, the farmer scouts fields periodically during the crop's life cycle to determine whether and when to implement pest control measures, based on presence/absence and populations levels of pest and beneficial insects, and on life stage and condition of the crop. In IWM, the farmer usually includes both preventive and control measures in preseason planning, designing an integrated strategy to give the crop as large a competitive edge over the weeds as practical. Weed scouting is conducted from before the crop is planted until after it is harvested to evaluate efficacy of measures already taken, assess weed–crop competition, and fine-tune timing and method of cultivation or other control tactics to prevent crop losses and minimize deposits to the weed seed bank.

With the exception of classical biological control of certain invasive exotic weeds by introducing insects imported from their areas of origin (e.g., purple loosestrife in wetlands; Klamath weed and certain exotic thistle species in rangelands of the western US), today's IWM rarely employs specific biological agents against specific weed species. However, IWM most certainly relies on biological processes as major components of the weed management strategy. The most obvious and vital of these are the direct competitive effects of well-managed, vigorous cash crops and cover crops against weeds. Other important biological components of IWM may include conservation biological control (protecting and providing habitat for ground beetles and other consumers of weed seeds or seedlings), allelopathic effects of cover crops, and the use of livestock to graze weeds. Cover cropping and other practices that enhance these biological components of weed management can also contribute to overall soil health and productivity.

Applying and Adapting IWM Concepts to Organic Weed Control

Successful organic weed management requires a more preventive approach to IWM (Sullivan, 2003), since organic production excludes the use of synthetic herbicides, and the few NOP-allowed natural herbicides now commercially available are usually not economically efficacious at a field scale. Without selective herbicides, it is especially difficult at any scale larger than the homestead garden to rescue a crop from weeds that have already begun to suppress the crop's growth and development. Careful planning, with a strong emphasis on preventive measures as well as timely cultivation and other control tactics, is essential.

Some cultural practices for organic IWM fulfill multiple functions. Diverse crop rotations reduce disease, insect pest, and weed pressures; enhance beneficial habitat; and balance nutrient demands on the soil. Cover crops feed and protect the soil, offer beneficial habitat, and improve nutrient availability, as well as suppress weeds. Organic mulches conserve moisture, add organic matter and sometimes nutrients, keep produce cleaner, and harbor ground beetles and other organisms that consume weed seeds and insect pests, as well as hinder weed seedling emergence. Grazing livestock can add manure without the work of hauling it, as well as remove weeds before they shed seed. Even timely, skilled cultivation can become multifunctional; for example a pre-emergence blind cultivation can facilitate crop emergence by breaking up soil crusts while knocking out recently emerged weeds.

When a control treatment is needed to deal with an insect pest outbreak, organic IPM mandates using the least toxic and least disruptive methods that are effective. Biological (e.g., purchase and release of beneficial insects) and physical (e.g., floating row cover) tactics are chosen first over any chemical intervention such as soaps or botanical pesticides. When the latter are needed, the least toxic and most narrow-spectrum materials are preferred. Within the context of organic IWM, this principle might be restated: when weed control measures become necessary, choose the least soil-erosive and least soil-disruptive tools and methods that would be effective.

By preventing weed problems from developing, organic IWM aims to reduce tillage needs through constant observation, fine tuning of crop rotations, and other proactive measures. As with biointensive IPM for other pests, organic IWM is inherently a site specific process, depending on a farm's crop mix, weed flora, soils, climate, available equipment and other resources, and market needs.

Case Study:
Beating the Weeds with Low-Cost Cover Crops, Intercropping, and Steel

David Stern of Rose Valley Farm grows a diversity of organic vegetables on 40 acres of mostly level cropland located a few miles from lake Ontario in upstate New York. Crops include 21 successional plantings of lettuce through the season, other greens, onions, garlic, leeks, winter squash, potatoes and other root vegetables including specialty crops like daikon radish and Oriental burdock. He also has one-half acre of blueberries, chestnuts, filberts, pears, and grapes as of 2006. He focuses on fall vegetables, which suffer less weed and insect pest pressure.

"Weeds are the Number One pest in our area," David began. "We don't have a lot of bugs. Our primary tool is cover cropping, and we use the steel when needed." He also uses plastic mulch on certain crops...

About one-third of the cropland is in cover crops at most points through the season. Main problem weeds include pigweed, galinsoga, johnsongrass, cocklebur, and hedge bindweed. For economy, David chooses locally-produced cover crop seed, such as buckwheat, which is processed at a nearby plant and is available at just $9 a bushel. Buckwheat nicely fills a 35-day window after spring spinach, and can give two successive crops from one seeding by letting the first set seed before tilling it in.

David relies heavily on rye–vetch and oats–winter peas, but where his vegetable rotation permits, he now drills oats in rows 7 inches apart at 150–180 lb/ac in mid August. The oats reach a height of four feet before winter-killing in December, and David is trying to develop practical, farm-scale methods for no-till planting of early spring vegetables into the oat residues.

Red clover is another major cover crop. David overseeds this clover into winter squash, and lets the clover grow through two seasons to reduce weed levels. Red clover can tolerate light levels as low as 6% of full sun. The clover seedlings "hang out" under the squash canopy, and are released to grow rapidly once the squash foliage is destroyed by harvest and mildew. He also spin-seeds red clover into sweet corn after the final cultivation (when corn is 24–30 inches tall). As soon as corn harvest is complete, David chops corn residues to a short stubble height, which releases the clover so that it can cover the ground within five days.

David has developed various vegetable–cover intercrop combinations to maximize biomass and minimize bare soil and weeds. Sweet potatoes are grown in black plastic, with buckwheat sown between rows at twice the normal rate. The buckwheat is mowed before seed-set and the sweet potato vines grow over the dead mulch. He has planted ladino clover as a living mulch between melons, mowing the clover just before vining. Spring peas are intercropped with broadcast proso millet (birdseed), and both millet and pea vines are incorporated after pea harvest.

David plants some vegetables, such as potatoes, in every other bed, with a mulch-generating cover crop of sorghum–sudangrass in the alternate beds. The sorghum–sudan strips are mowed, and the clippings are blown into the adjacent rows of potatoes. Oats are spin-seeded into fall brassica crops to reduce winter erosion and enhance trafficability. David has modified a push mower for managing living mulches, by mounting relatively large wheels in front and back to give greater flexibility of mowing heights.

Sometimes David intercrops two vegetables to make the best use of space early in the season. Late-season vining crops like winter squash need good weed control early in the season, and David has had trouble with rodent damage to the crop when he used mulch. Instead, he plants beet greens, mustard or other greens between newly-planted butternut squash rows, and harvests the greens before the squash vines spread. In this system, he only needs to cultivate once.

Weed control in organic perennial crops like asparagus can be a real challenge. David found that heavy mulching can increase slug and asparagus beetle problems, so he mows shortly after the end of harvest, discs lightly to break the soil surface, then plants soybeans, which suppress weeds without interfering with asparagus fern growth.

Garlic thrives in mulch, and requires nonmechanical harvest. David unrolls round hay bales after planting garlic. In the following season, the mulch keeps the soil cool, which prolongs garlic growth and enhances yield. Many garlic farmers are now planting oats about four to six weeks prior to garlic planting, which helps prevent soil erosion that can result from bare ground planting in the fall.

When it is time to roll out the steel, David uses Buddingh basket weeders to remove tiny weeds in the “white thread” stage. The baskets work only 1/8 to ¼ inch deep, with front and rear baskets rotating at different speeds to enhance weeding action. He uses several other implements for larger weeds. In young crops, he uses a weeder with vibrating, spring-loaded tines whose tension and depth can be adjusted to simulate rotary hoe action. The Lilliston rolling basket cultivator can be adjusted to shape beds as it weeds, and the Regi weeder is an aggressive PTO-driven device with two rotary disks with hayrake teeth, guided manually from behind, that can effect within-row weeding. David also mentioned the Multivator, a multiple-head rototiller that gives great flexibility to weed between crop rows, but noted that it is hard on soil structure, so he avoids frequent use.

In some cases, he manages weeds and prevents weed seed set by mowing. The mowed weeds act as a green manure and can contribute to soil fertility.

David has designed two implements that combine the efficiency of tractors with the fine precision of the human eye and hand, which he describes as “the most accurate weeding tool we have.” The platform weeder/harvester is a homemade platform on a three-point hitch that adjusts so a person can lie comfortably on a foam mat and handweed crops (small to large) as the tractor moves slowly through the field. The wiggle hoe is a three-point tractor-mounted tool modified from the horse-drawn cultivators of our grandfathers. A person sits comfortably, directly over a row of vegetables, and with handheld, mounted tools, can very accurately and closely cultivate at a shallow depth. The wiggle hoe is similar to the Regi weeder, but it is not as aggressive.

David emphasized that his experience and his presentation should not be taken as a recipe for others to follow to the letter. “Following someone else’s prescription is dangerous,” he cautioned. “You need to be creative, take a site specific approach, and develop a rotation and weed management strategy for your own farm.” This may be especially true when adapting a system like David’s to an entirely different climatic zone, such as the Tidewater region of Virginia. However, the underlying principles of weed, crop and soil management still apply, and the longer growing season and milder winters of the South may open an even wider range of cover crop species and cropping strategies for year-round organic weed management.

In conclusion, he advised:

- Know your weeds, their life cycles, and why they are on your farm.
- For tractor cultivation, take wrenches into the field so you can adjust the tool and anti-sway bars to maximize efficiency of time and fuel use.
- Cultivate early in the morning on sunny days.
- NEVER let weeds go to seed. One mature pigweed can bless the farm with 400,000 seeds!

This case study is reprinted with permission from: ***Schonbeck, M. 2007. Beating the weeds with low-cost cover crops, intercropping and steel. The Virginia Biological Farmer 30: 7–8.*** *It is based on a presentation by David Stern of Rose Valley Farm in Rose, NY given in Abingdon, VA on 2 December 2006. is based on a presentation by David Stern of Rose Valley Farm in Rose, NY, given at the Organic Growers' School of the Appalachian Regional Horticulture Conference in Abingdon, VA on December 1–2, 2006.*

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables**. See also **An Ecological Understanding of Weeds**.

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Knock Weeds Out at Critical Times

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Introduction

The “control” part of organic weed management aims to remove weeds that threaten current or future production at the least possible cost in labor, fuel, machinery and potential harm to the soil. Trying to eliminate every weed on the farm would likely lead to red ink, and can defeat efforts to build healthy soil. Thus, the farmer must continually evaluate: do I need to kill the weeds in *this* crop *now*? When are the critical times for weed control during the course of the season?

One criterion might be: “whenever weeds are about to curb crop growth and yield.” Home gardeners often use this guideline with some success, gathering a lot of free mulch or compostable biomass as they pull or cut all those big weeds. However, on a farm scale, this is simply too late, as the effort required to rescue the crop could again eat up profits or degrade the soil. For the organic farmer, *critical times for weed control a*re those points at which cultivation or other measures will most effectively protect current and future crops from the adverse effects of weeds. Critical times include:

- When the crop is planted
- When flushes of weed seedlings are just emerging
- During the crop’s minimum weed-free period
- When perennial weed reserves reach their minimum
- Before weeds form viable seed or vegetative propagules

Start with a Clean Seedbed

Weeds that emerge before or with the crop have a greater impact on crop yield than later-emerging weeds. Planting into a clean, weed-free field is essential. Remember that an apparently clean seedbed prepared just a few days before the vegetable is planted may have millions of germinating weed seedlings per acre that have not yet visibly emerged (Fig. 1). Whenever possible, plant *immediately* after the final step in preparing the ground – whether that step is harrowing, rototilling, incorporating amendments, shaping the beds, or strip-tilling the crop rows.

Figure 1. This seedbed was prepared a few days before the photo was taken (left). It may seem clean enough, but stir the surface lightly and look again! (right). A very shallow cultivation immediately before planting can knock out a lot of these newly-germinating weeds resulting in a cleaner seedbed. Photo credit: Mark Schonbeck, Virginia Association for Biological Farming.

For many crops, blind cultivation can be used to keep the seedbed clean until the crop is up. Larger-seeded vegetables can be rotary-hoed to give them a head start. Weed seedlings that beat slow-germinating crops like carrot to the punch can be removed by flaming. Some farmers time this operation by covering a small patch with a pane of glass. When the crop first emerges under the glass, the field is flame-weeded. The rest of the crop then emerges a day or two later, in a clean field.

Get the Weeds When They are Small

The smaller the weed, the easier it is to kill through light cultivation or flame weeding. Early in the growing season when large “flushes” of weeds often emerge, many farmers do a very shallow cultivation when weeds are in the “white thread” stage or are just emerging (long before the weeds begin to compete with the crop), rather than waiting until the field is visibly weedy. Shallow cultivation often pays because it:

- Minimizes damage to soil structure and soil life
- Minimizes light-stimulated germination of additional weeds
- Requires less fuel and less effort
- Can kill millions of newly emerging weeds per acre

This approach may be especially advantageous during early stages of crop establishment and growth (Fig. 2). Cultivate before weeds get more than an inch tall. Some weeds develop an incredible ability to reroot and survive light cultivation once they pass this stage. Weeds two to three inches tall require more vigorous cultivation, which consumes more fuel, disrupts soil structure, and stimulates additional weed seed germination.

Figure 2. This basket weeder works only a fraction of an inch deep, removing tiny weeds from between these rows of young brassica plants. Photo credit: Mark Schonbeck, Virginia Association for Biological Farming.

One possible disadvantage to this “proactive” approach to timely cultivation is that it can result in multiple passes through the field to keep removing small weeds until the crop is established. An alternative strategy, which strives to minimize the frequency rather than depth of cultivation, may be appropriate in certain circumstances (See Sidebar).

Many good tools and implements have been developed for shallow between-row and within-row cultivation for different vegetable crops at various stages of development.

Sidebar:
Avoiding Overcultivation: Minimum Versus Critical Weed-Free Periods.

Weed scientists and farmers have a couple ways of estimating when cultivation is most important for keeping weeds from hurting the current crop. One is to ask how long after crop planting can weeds be allowed to grow before they must be removed (the “maximum weed-infested period”). Another is to ask how long the crop must be kept clean before later-emerging weeds can be allowed to remain (the “minimum weed-free period”). A third is to determine the stage(s) of development in which the presence of weeds is most likely to hurt yields (the “critical period of weed competition” or “critical period for weed control”).

Assuming that the crop is planted into a clean seedbed, germinating crops and weeds start their “race” at the same time. Weeds that germinate with the crop usually do not affect the crop’s growth until two or three weeks after emergence – when they first become large enough to begin competing for moisture and nutrients. This initial “grace period” during which weed can grow without reducing the crop’s yield potential is the *maximum weed-infested period*. The farmer needs to cultivate or otherwise control weeds before the end of this period.

Weeds that emerge with or shortly after the crop have the greatest potential for causing economic damage if allowed to grow unchecked. Later emerging weeds have less effect, and those that emerge after a certain point in time no longer affect yield. This point is the *minimum weed-free period*.

The interval from the end of the maximum weed-infested period until the end of the minimum weed free period defines the *critical period for weed control* for the crop. Since the crop can be adversely affected either by early-emerging weeds allowed to persist into this period, or by weeds emerging during this period and allowed to grow, the weed control strategy should focus on keeping the crop clean through this time. If cultivation is limited to one or two passes, it must be strategically scheduled within this period, and implements designed to be effective against the largest weeds present must be used. Possible advantages to this approach include:

- Less labor and machinery time is expended on weed control
- Fewer operations are easier to schedule
- Less frequent disturbance of the soil surface can mean less surface crusting and erosion
- Larger weeds leave more residue that can further protect soil surface from degradation

However, this approach can be risky especially in vegetable crops that are not highly competitive or have long critical periods for weed control (e.g., carrot), or that need to be quite clean at harvest (e.g., mesclun, baby lettuce). When cultivation is delayed until the beginning of the critical period for weed competition, the farmer depends on favorable conditions for effective cultivation at that time. If an untimely rain falls, the additional delay will likely result in a significant yield loss. Therefore, most Extension agents and consultants advise organic vegetable growers to “get weeds while they are small," especially early in crop development.

Keep the Crop Clean Through its Minimum Weed-Free Period

Once the early flushes of weeds have been knocked out, continue monitoring and controlling later-emerging weeds until the crop has passed through its minimum weed-free period. For vigorous vegetables this period is generally the first one-third of the crop’s growing season, or four to six weeks for crops like tomato, squash, cucumber, snap bean, and transplanted brassicas; and perhaps a little longer for eggplant and pepper. Less vigorous crops like onion or carrot may need weed-free conditions for at least the first half of their life cycle, perhaps eight weeks or more.

How "clean" is clean enough during this period? Crops differ in their inherent weed tolerance even during the minimum weed-free period. Slow-growing, weed-sensitive vegetables like parsley, direct-sown onion or carrot can suffer if weeds are allowed to reach the two-leaf stage before cultivation. Thus, it may pay to "cultivate early and often," knocking weeds out in the white-thread stage until the crop is well established. In vigorous crops like beans, sweet corn, or potatoes, one early cultivation and a second pass to remove later-emerging weeds at the two-leaf stage or even a little larger, may be sufficient.

While the crop is still small, those weeds emerging closest to crop plants compete most severely. Therefore, cultivation must effectively remove within-row weeds, as well as weeds between rows. Timing is critical for mechanical within-row weeding, which works only when the weeds are tiny and the crop is sufficiently large that it can withstand the effects of light cultivation. Later in the minimum weed-free period, the growing crop begins to shade out emerging within-row weeds, while weeds emerging between rows can still grow unimpeded and pose a threat. At this point, some vegetables can be cultivated with a between-row implement adjusted to throw some earth into the row to bury and thereby hinder small within-row weeds. This works well for potato, corn, tomato, broccoli, and other tall vegetables that tolerate hilling-up, but of course not for lettuce, spinach, and other vegetables whose edible parts form close to the ground.

Hit Perennial Weeds When Their Reserves are Low

Invasive or wandering perennials like quack grass, nutsedge and Canada thistle that reproduce through a propagating network of rhizomes, roots, stolons, tubers or bulbs are often the most difficult to manage. An initial tillage pass deep enough to chop up these structures will effectively propagate the weed, as each fragment soon regenerates a new plant. However, these plants are weaker than the larger plants growing from undisturbed underground structures. During the first three or four weeks after fragmentation, the pieces of root or rhizome draw down their underground reserves in order to regenerate shoot growth. One the growing weeds each have several open leaves, they begin rebuilding reserves through photosynthesis. Soon thereafter, they can begin to form new rhizomes, bulbs, tubers, or other vegetative propagules.

Additional tillage, or even simply removing top growth, whenever the weeds reach the three to four leaf stage can be quite effective in further weakening invasive perennial weeds (Fig. 3). The farmer may need to do this several times at three or four week intervals to knock out a serious infestation. Planting buckwheat or other “smothering” cover crops at high seeding rates immediately after tillage intensifies pressure on the weed, and can get the job done faster with fewer tillage passes.

Figure 3. This bed was tilled just before setting out the broccoli, which fragmented some of the roots of a localized Canada thistle infestation. Severed roots and fragments have now regenerated new plants, which are getting large enough to begin rebuilding reserves. Immediate cultivation or hoeing is needed to continue the process of weakening this invasive perennial weed. Photo credit: Mark Schonbeck, Virginia Association for Biological Farming.

When wandering perennial weeds emerge in a vegetable crop, cultivate to sever top growth whenever the weeds reach this critical three to four leaf stage. Sharp sweeps or knives set to work just below the soil surface will do the job.

Prevent Weed Propagation

Once the crop has passed through its minimum weed-free period, weed control need not be so stringent. However, it is vital in organic production systems to *prevent weeds from forming viable seeds*. Four consecutive years of preventing all weed seed return can substantially reduce population density of the spring and early summer flushes of weed emergence. While this can be difficult to achieve at the farm scale, efforts to minimize weed seed formation pay off in lower weed densities in the long run.

Late-emerging weeds are easy to manage in quick-maturing vegetables that are harvested before these weeds have a chance to flower. Simply till or mow promptly after harvest and before weeds set seed. Growing several short-season vegetables in quick succession is one way to limit weed propagation and can even draw down weed seed populations in the soil (weed seed bank).

In longer-season vegetables, additional measures are often needed to prevent these later weeds from setting seed, such as between-row mowing or cultivation, or manual pulling or cutting. As soon as harvest is complete, mow or till to terminate any further weed propagation. Weeds that have become overshadowed by the crop canopy may form relatively few seeds, whereas large, emergent “escapes” can make huge deposits into the soil’s weed seed bank and create major weed problems for future seasons. It often pays to “walk the fields” to rogue-out the large weeds before they release thousands of mature seeds each (Fig. 4). Remember that an uprooted or severed weed can often finish ripening immature seeds, so get the weeds *before* pollination occurs, or remove them from the field.

Figure 4. These pigweeds came up late enough and far enough from the summer squash not to have any effect on the size or quality of the harvest that is about to begin. However, time taken to pull or chop out these plants before they mature can pay off severalfold by preventing a large "deposit" into the field's weed seed bank. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Pay attention to invasive or wandering perennials, many of which actively form their “seed” underground by the time top growth is a foot tall. Even when it is not practical to prevent their propagation altogether, vigorous cultivation or close mowing between crop rows, and over the entire field immediately after harvest, will limit the formation of viable rhizomes and tubers.

When Weeds Seem Out of Control

If weeds seem to "take over" a particular field, it usually means that insufficient attention has been paid to weed management over a period of time. Missing one or more critical times for weed control during a particular season can result in weeds gaining the upper hand over the crop. Allowing weeds to propagate can mean higher weed population densities that are harder to control the following season. When weeds tend to "take over" despite diligent and timely cultivations, more attention to *preventive* (cultural) weed management practices is needed. These may include adjusting the crop rotation to disrupt weed life cycles, increasing the use of cover crops, improving soil nutrient management to favor the crop over weed growth, or even rotating a weedy field out of production into a perennial grass-clover sod for a few years.

Invasive, vegetatively reproducing perennials can be especially difficult to manage, and can occasionally get out of control despite a diligent, integrated weed management program. If a heavy infestation develops, hit the weeds *repeatedly* when their underground reserves reach their minimum (when shoots have three to four leaves). Planting a fast-growing, highly competitive cover crop like buckwheat, cowpea, or rye + field pea immediately after the second or third tillage can further delay regeneration by the now-weakened perennial weeds, as well as helping to restore soil organic matter and soil quality lost through repeated tillage.

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables**. For more information on organic weed control tools and methods, see **An Organic Weed Control Toolbox**.

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Weed Seedbank

Summary of Viable Weed Seeds Density Trials (UD summary)

Sources Contributing to Weed Infestations (UD summary)

Weed Seedbank Dynamics and Integrated Management of Agricultural Weeds (MTSU)

Manage the Weed Seed Bank (eXtension)

Weed Seed Predation in Agricultural Fields (ISU)

Don’t Plant Weeds with Your Winter Rye: weed seed contamination can spell disaster (MSU)

Summary of viable weed seeds in soil

Sample depth 6 to 8 inches

Country	Crops sequence	Range number of seeds ft^{-2}		No. of fields	Reference
Poland	Onions	1040	1932	100	Lewandowska and Skapski (1979)
United Kingdom	Vegetables	258	4350	1	Roberts (1963)
	Vegetables	129	301	1	Roberts (1968)
	Vegetables	23	2260	89	Roberts and Neilson (1982)
	Cereals	774	6814	1	Brenchley and Warington (1930)
	Cereals		2667	2	Brenchley and Warington (1933)
	Cereals	1192	4084	1	Brenchley and Warington (1945)
	Vegetables	151	7990	58	Roberts and Stokes (1966)
	Various	167	622	32	Lockett and Roberts (1976)
	Various	279	5156	32	Chancellor (1981)
Canada	Fallow/wheat/fallow	441	2131	??	Budd et al. (1954)
Germnay	Cereals		1645	??	Hurle (1974)
United States	Corn/s. beet/barley	193	12105	1 (6-yr perioc	Schweizer and Zimdahl (1984)
	Corn	37	7228	3	Cardina et al (1991)
	Field crops	56	1505	8	Forcella et al (1992)
Hungary	Corn	511	1385	??	Fekete (1975)
	Corn		1984	??	Fekete (1975)
	Corn		1785	??	Fekete (1975)
Denmark	Root crops	56	116593	20	Jensen (1969)
	Cereals	204	46098	37	Jensen (1969)

From: Christoffoleti, P., S.J. Pinto de Carvalho, M. Nicola, D. Doohan, and M. VanGessel. 2007. Prevention strategies in weed management. In Non-chemical weed management: principles, concepts, and technology, Editors: Mahesh Upadhyaya and Robert Blackshaw. CABI, Oxfordshire, UK

Table 1.1 Various sources contributing weed seed based on studies attempting to quantify input of weed seeds.

Seed source	Estimated number of seeds per A*	Number of species collected	Citation
Irrigation water	19,600	34	Wilson, 1980
Irrigation water	4,000 to 38,000	137	Kelley and Bruns, 1975
Irrigation water	37	4	Dastgheib, 1989
Dairy farms	37,000 to 400,000**	na	Cudney *et al*., 1992
Dairy farms	1,400,000***	48	Mt. Pleasant and Schlather (1994)
Sheep pasture	4,000,000	92	Dastgheib, 1989
Cattle pens	2,150,000****	23	Rupende *et al*., 1998
Wheat, saved seed	74,000	11	Dastgheib, 1989

Irrigation water was from open irrigation canals.

*Based on authors estimates or 22 tons per hectare for manure as a fertilizer source.

**Seven dairies were sampled.

***Twenty farms were sampled: four farms had no detectable seeds, and only one farm had >200,000 seeds per ton of manure. Value presented is mean of sixteen farms with weed seeds at 75,100 seeds per ton.

****Four farms sampled.

A Self-Learning Resource From MSU Extension

MONTANA STATE UNIVERSITY EXTENSION

MontGuide

MT200808AG Reprint 10/08

Weed Seedbank Dynamics & Integrated Management of Agricultural Weeds

by Fabian Menalled, Department of Land Resources and Environmental Sciences, Montana State University-Bozeman

Weed seed production from early surviving plants and late emerging individuals has the potential of creating future weed problems. Integrated weed management programs should include approaches to deplete the reservoir of weed seeds present in the seedbank.

What is the weed seedbank?

The weed seedbank is the reserve of viable weed seeds present on the soil surface and scattered in the soil profile. It consists of both new weed seeds recently shed and older seeds that have persisted in the soil for several years. Agricultural soils can contain thousands of weed seeds per square foot and understanding the factors impacting the dynamics of weed seedbanks can help in the development of integrated weed management (IWM) programs.

The weed seedbank not only serves as a physical history of the past successes and failures of cropping systems, it can also help producers predict the degree to which crop-weed competition will affect crop yield and quality.

This MontGuide:

- Describes the fate of weed seeds after being shed
- Explains how management decisions affect the weed seedbank
- Discusses the importance of minimizing inputs into the seedbank
- Provides weed seedbank management strategies

What happens with weed seeds after shed?

Weed seeds can reach the soil surface and become part of the soil seedbank through several avenues. The main source of weed seeds in the seedbank is from local matured weeds that set seed. Agricultural weed seeds can also enter a field by animals, wind, water and human activities, like cultivation and harvesting. How far weed seeds can travel depends on the dispersal process and the weed species (Figure 1). Understanding the importance of these dispersal mechanisms is vital in the development of preventive weed management strategies.

Weed seeds can have numerous fates after they are dispersed into a field (Figure 2, page 2). While a few of these weed seeds will germinate, emerge, grow and produce more seeds, a large proportion of them will germinate and die (also know as fatal germination), decay in the soil, or fall to predation by insects, birds or mammals. Many weed seeds will remain dormant in the soil and not germinate under any set of environmental conditions. When a weed seed is dormant it will not germinate regardless of the environmental condition. This dormancy state is not permanent and weed seeds can change from a state of dormancy to non-dormancy, where they can germinate over a wide range of environmental conditions. Because dormancy can create future weed problems, weed scientists think about dormancy as a dispersal mechanism through time.

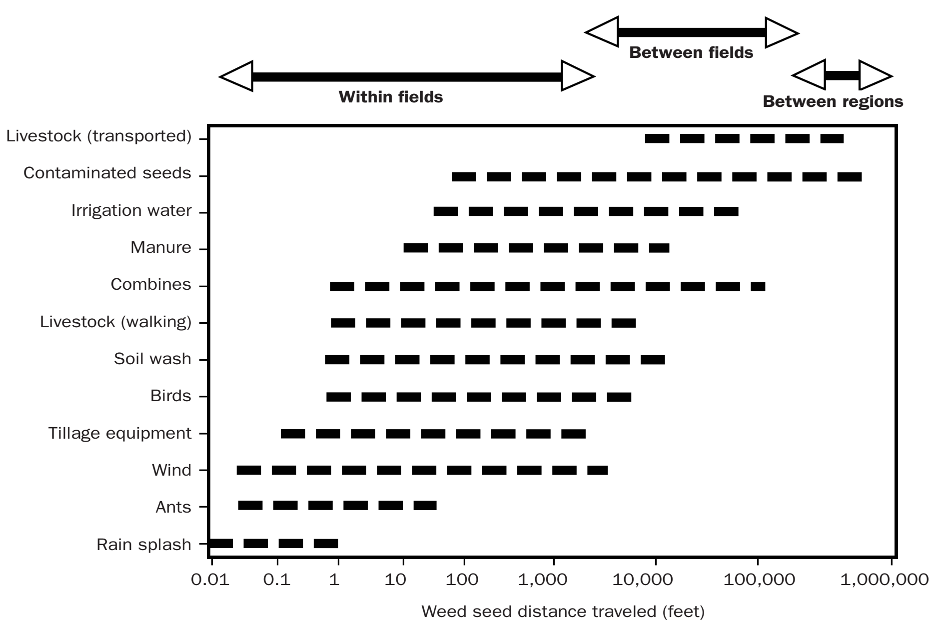


FIGURE 1. Agricultural weed seeds can travel over a range of distances, depending on the method of transport and the weed species. Adapted from Mohler (2001).

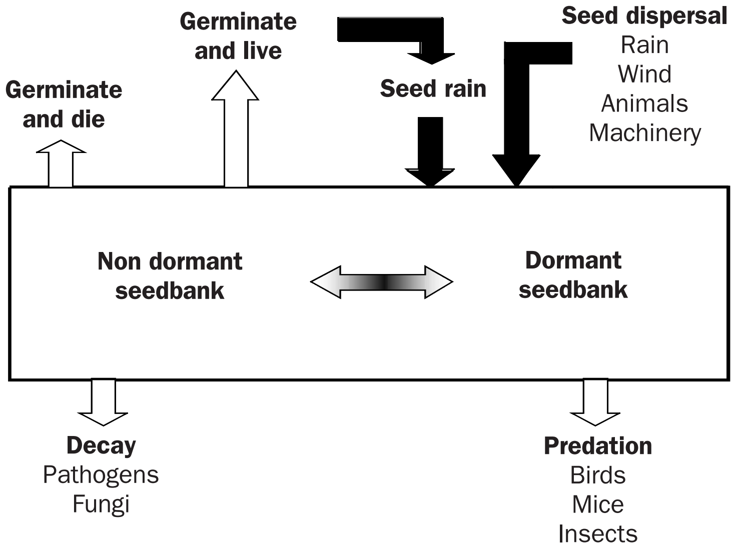
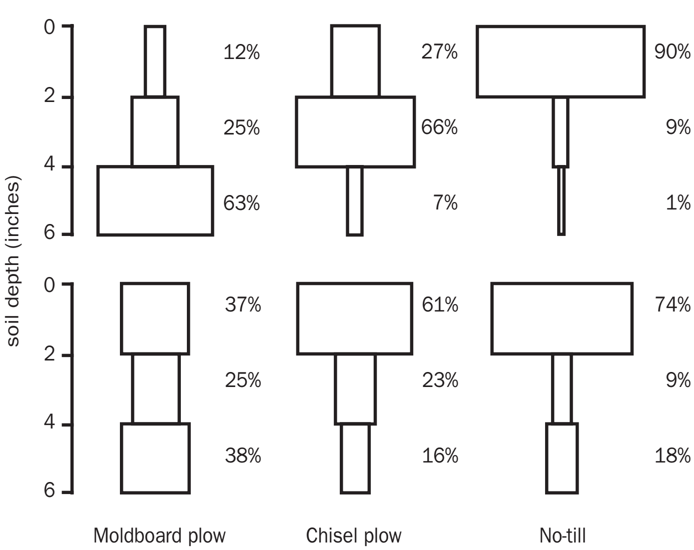


FIGURE 2. Fate of weed seeds. Inputs to the seedbank are shown with black arrows and losses with white arrows.

How do management practices affect weed seed distribution in the soil profile?

Weed seeds disperse both horizontally and vertically in the soil profile. While the horizontal distribution of weed seeds in the seedbank generally follows the direction of crop rows, type of tillage is the main factor determining the vertical distribution of weed seeds within the soil profile. In plowed fields, the majority of weed seeds are buried four to six inches below the surface. Under reduced tillage systems such as chisel plowing, approximately 80 to 90 percent of the weed seeds are distributed in the top four inches of the soil profile. In no-till fields, the majority of weed seeds remain at or near the soil surface. Although very few studies have assessed the affect of tillage systems on the vertical distribution of weed seeds in different soil types, evidence exists that soil characteristics influence weed seed distribution (Figure 3).

FIGURE 3. Vertical distribution of weed seeds in a loamy sand soil (top) and a silty loam soil (bottom). Adapted from Clements et al. (1996).



Understanding the impact of management practices on the vertical distribution of seeds is important as it can help us predict weed emergence patterns. For example, in most soils small-seeded weeds such as kochia, Canada thistle and common lambsquarters germinate at very shallow depths (less than ½ inch). Large seeded weeds such as common sunflower have more seed reserves and may germinate from deeper depths.

How long does weed seed persist in the seedbank?

Seed longevity in the soil depends on the interaction of many factors including the intrinsic dormancy of the seed population, the environmental conditions (e.g. light, temperature, moisture) and biological processes (e.g. predation, allelopathy). Understanding how management practices or environmental conditions modify the residence time of viable seeds can help producers to minimize future weed problems. For example, tillage enhances seed longevity as weed seed usually remain viable longer if they are buried. On the other hand, no-till reduces seed persistence by exposing them to predators and pathogens.

Although research has shown that agricultural weed seeds of some species may remain viable for several years, most weed seeds will either germinate or die shortly after being dispersed from the parent plant (Table 1). In a field study conducted near Bozeman, wild oat seeds were incorporated into the top four inches of a wheat-fallow field and approximately 80 percent of them died during the first winter (Figure 4).

Why is it important to prevent weed seed production?

Limiting current contributions to the weed seedbank is the best approach to ease future weed management. Over a five-year period in Nebraska, broadleaf and grass weed seedbank was reduced to 5 percent of the original density when weeds were not allowed to produce seeds. However, in the sixth year, weeds were not controlled and the seedbank density increased to 90 percent of the original level (Burnside et al., 1984)!

In a six-year study conducted in Canada, Beckie and collaborators (2005) observed that when standard weed management practices were combined with weed seed shed prevention, weed patches expanded in size by 35 percent. However, when only standard weed management approaches were applied, weed patch expansion reached 330 percent (Figure 5).

These studies illustrate three important points. First, seedbank abundance declines rapidly when no new weed seed are allowed to enter to soil. Second, management failures can translate into a rapid increase in weed seedbank

TABLE 1. Number of years required for 50 percent and 99 percent reduction in seed number in the seedbank of ten common agricultural weeds. Adapted from Davis et al. (2005).

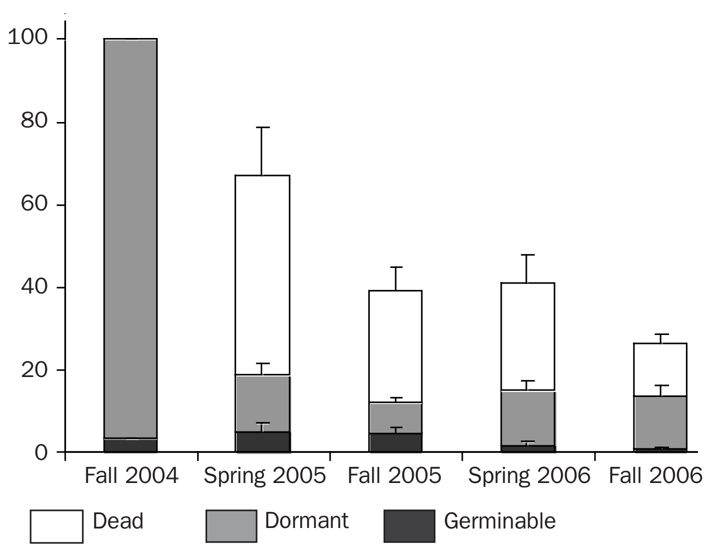
	Years required for 50% reduction	Years required for 99% reduction
Common lambsquarters (*Chenopodium album*)	12	78
Field pennycress (*Thlaspi arvense*)	6	38
Common cocklebur (*Xanthium strumarium*)	6	37
Yellow foxtail (*Setaria glauca*)	5	30
Prostrate knotweed (*Polygonum aviculare*)	4	30
Shepherd's purse (*Capsella bursa-pastoris*)	3	11
Giant foxtail (*Setaria faberi*)	less than 1	5
Common sunflower (*Helianthus annuus*)	less than ½	2
Kochia (*Kochia scoparia*)	less than ½	2

abundance. Finally, preventing weed seed production not only helps reducing weed seedbanks, it prevents the spread of weeds across the field. Therefore, efforts should be made every year to reduce seed production and weed seedbank abundance as a few seeds are capable of infesting the fields.

Managing the weed seedbank

The reproductive potential of agricultural weeds coupled with the persistence of weed seeds in the seedbank indicates that management strategies should not only focus on minimizing weed density and yield reductions, they should also include approaches to minimize weed seedbanks.

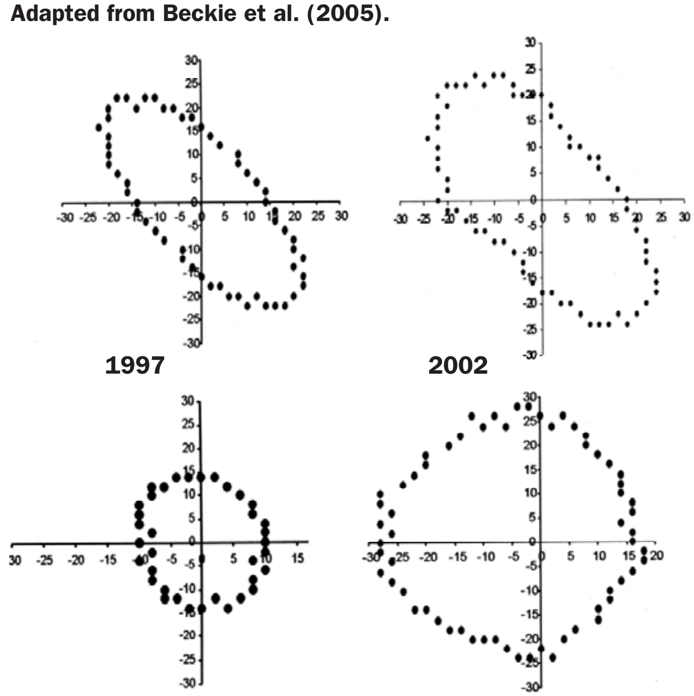
FIGURE 4. Wild oat seedbank dynamics. Seeds were mixed within the first 4 inches of the soil in October 2004 in a wheat-fallow field. Soil samples were obtained in early spring and late fall of 2005 and 2006. Wild oat seeds were extracted from the soil samples and classified as dead, alive but dormant and germinable. Adapted from Harbuck (2007).



The study of weed seedbank composition and dynamics is a relatively new concept in weed science. Still, several management practices can be implemented to deplete the seedbank reservoir.

• ***Prevention.*** The most efficient approach to reduce weed seedbanks is to not allow weeds to set seed in the field. Care should be taken to avoid bringing new weed seeds into a field through irrigation, equipment or animals. This can be achieved by screening irrigation water, washing equipment before bringing it into the field and keeping grazing animals in quarantine before moving them from a weedy field to a clean one.

FIGURE 5. Weed patch expansion can be minimized by preventing weed seed inputs into the seedbank. During a five year period, a weed patch expanded 35 percent in size when standard weed management practices were combined with efforts to prevent seed production (top). During the same period, a weed patch expanded 330 percent in size when only standard weed management practices were applied (bottom). Adapted from Beckie et al. (2005).



• ***Reduction.*** Reduction not only minimizes future weed problems, it also reduces the speed at which weed patches expand across crop fields. Increasing crop interference by increasing seeding rate and filling empty niches with cover crops helps minimize weed seed inputs into the seedbank. Other approaches include mowing weeds prior to seed production and controlling weeds with herbicides or cultivation.

• ***Seed longevity.*** While burying weed seeds by tilling increases the longevity of the seeds in the seedbank, leaving weed seeds on the soil surface exposes them to predation, reducing their abundance in the seedbank.

• ***Rotation.*** Rotation can cause a shift in weed species composition. Knowledge of theses shifts can help in changing the composition of the weed seedbank from undesirable to easy-to-manage species.

• ***Manure.*** Composting manure reduces the viability of weed seeds, minimizing weed seed inputs into the seedbank.

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For further information on Integrated Weed Management (IWM) read MSU Extension MontGuide *Integrated Strategies for Managing Agricultural Weeds: Making Dropping Systems Less Susceptible to Weed Colonization and Establishment* (MT200601AG) that is available from your local Extension office.

Did you know? Insects, birds, and rodents are your allies. Many studies have shown they can eat large quantities of weed seeds before (predispersal) or after (postdispersal) being shed from the parent plant. Combining field data with simulation models, Westerman and collaborators (2005) showed that herbicides and cultivation could be substantially reduced in a diverse crop rotation that had high levels of seed predation, compared to a simple rotation with lower rates of predation.

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File under: Agriculture and Natural Resources (Weeds)
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Manage the Weed Seed Bank—Minimize "Deposits" and Maximize "Withdrawals"

Last Updated: March 23, 2010

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One of the most important—yet often neglected—weed management strategies is to reduce the number of weed seeds present in the field, and thereby limit potential weed populations during crop production. This is accomplished by managing the weed seed bank.

What is the Weed Seed Bank, and Why is it Important to Organic Farmers?

The weed seed bank is the reserve of viable weed seeds present on the soil surface and scattered throughout the soil profile. It consists of both new weed seeds recently shed, and older seeds that have persisted in the soil from previous years. In practice, the soil's weed seed bank also includes the tubers, bulbs, rhizomes, and other vegetative structures through which some of our most serious perennial weeds propagate themselves. In the following discussion, the term **weed seed bank** is defined as the sum of viable weed seeds and vegetative propagules that are present in the soil and thus contribute to weed pressure in future crops. Agricultural soils can contain thousands of weed seeds and a dozen or more vegetative weed propagules per square foot.

The weed seed bank serves as a physical history of the past successes and failures of cropping systems, and knowledge of its content (size and species composition) can help producers both anticipate and ameliorate potential impacts of crop–weed competition on crop yield and quality. Eliminating "deposits" to the weed seed bank—also called **seed rain**—is the best approach to ease future weed management. Over a five-year period in Nebraska, broadleaf and grass weed seed banks were reduced to 5 percent of their original density when weeds were not allowed to produce seeds. However, in the sixth year, weeds were not controlled and the seed bank density increased to 90 percent of the original level (Burnside et al., 1986).

Weed seed banks are particularly critical in organic farming systems, which rely on cultivation as a primary means of weed control. Because a cultivation pass generally kills a fixed proportion of weed seedlings present, a high initial population will result in a high density of weeds surviving cultivation—**escapes**—and competing with the crop. Initial weed population is directly related to the density of seeds in the seed bank (Brainard et al., 2008; Teasdale et al., 2004); thus, effective cultivation-based weed control requires either a low seed bank density (Forcella et al., 1993) or multiple cultivation passes to achieve adequate weed control. In addition, dense weed stands (for example, a "sod" of smooth crabgrass or other grass weed seedlings) can interfere with the efficacy of cultivation implements in severing or uprooting weeds (Mohler, 2001b).

Cultivation efficacy—**weed kill**—can vary considerably based on equipment, soil conditions, weed growth stage, and operator experience. Eighty percent mortality would be considered quite respectable, a level of weed control far less than that achieved with most herbicides. Therefore, without the “big hammer” of selective herbicides to remove heavy weed populations from standing crops, effective measures to reduce weed seed banks become vital for the organic farmer.

Inputs (“Deposits”) and Losses (“Withdrawals)

Organic growers aim to manage their weed seed banks in the opposite fashion from a long term savings account: minimize “deposits,” and maximize “withdrawals” (Forcella, 2003). Weed seed bank deposits include:

- The annual weed seed return (or seed “rain”) from reproductively mature weeds in the field or in field margins
- Production of new rhizomes, tubers, and other vegetative reproductive structures by perennial weeds
- Weed seeds brought into the field through inputs and farm operations, such as manure, mulch hay, irrigation water, farm machinery, and custom operators
- Weed seeds introduced by natural forces beyond the farmer’s control, such as wind, floodwaters, and migrating birds

Whereas the first two kinds of deposits have the greatest influence on future population levels of *existing* weed species, the latter two can introduce *new* weed species to the farm—somewhat analogous to opening a new kind of bank account with a small initial deposit and a sky-high interest rate. Even two or three viable seeds or propagules of a highly aggressive new weed species can spell trouble in years to come. Thus organic farmers strive both to prevent heavy deposits through propagation of existing weeds, and to prevent establishment of new weed species by excluding their seed and promptly eradicating new invaders. This topic is discussed further in **Keeping New Weedy Invaders Out of the Field**.

Weed seed bank withdrawals include:

- Seed germination
- Fatal germination, in which the seed or propagule sprouts but fails to reach the soil surface due to excessive depth or death from allelochemicals (natural phytotoxic substances released by plants), microbial pathogens, insects, or other organisms in the soil
- Consumption of weed seeds by ground beetles, crickets, earthworms, slugs, field mice, birds, and other organisms (=weed seed predation)
- Loss of viability or decay of seeds over time

The first type of withdrawal—germination leading to emergence—is, of course, how weeds begin to compete with and harm crops each season. It is also the foremost mechanism for debiting the seed bank, an effective strategy if emerged seedlings are easily killed by subsequent cultivation or flaming (the stale seedbed technique, for example). Even in species with relatively long-lived seeds such as pigweeds, velvetleaf, and morning glory, the vast majority of weed emergence from a given season's seed rain takes place within two years after the seeds are shed (Egley and Williams, 1990). Thus, timely germination (when emerging weeds can be readily killed) can go far toward minimizing net deposits into the seed bank from recent weed seed shed. Knowing when to promote or deter weed seed germination, and how to do so for the major weeds present, are important skills in seed bank management.

Weed Seed Bank Dynamics

Weed seeds can reach the soil surface and become part of the soil seed bank through several avenues. The main source of weed seeds in the seed bank is from local matured weeds that set seed. Agricultural weeds can also enter a field on animals, wind, and water, as well as on machinery during activities like cultivation and harvesting (explored further in **Keeping New Weedy Invaders Out of the Field**).

Weed seeds can have numerous fates after they are dispersed into a field (Fig. 1). Some seeds germinate, emerge, grow, and produce more seeds; others germinate and die, decay in the soil, or fall to predation. The seeds and other propagules of most weeds have evolved mechanisms that render a portion (a large majority in some species) of propagules **dormant** (alive but not able to germinate) or **conditionally dormant** (will not germinate unless they receive specific stimuli such as light) for varying periods of time after they are shed. This helps the weed survive in a periodically disturbed, inhospitable, and unpredictable environment. Weed seeds can change from a state of dormancy to nondormancy, in which they can then germinate over a wide range of environmental conditions. Because dormant weed seeds can create future weed problems, weed scientists think of dormancy as a dispersal mechanism through time.

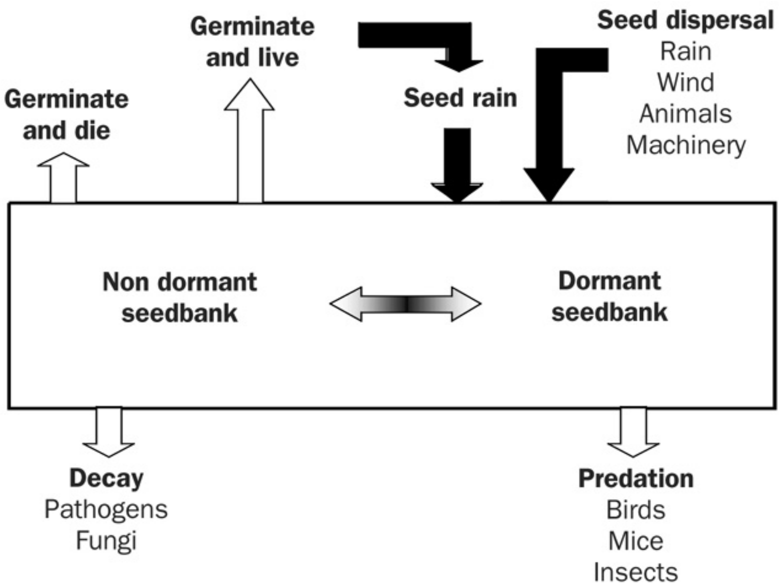

Figure 1. Fate of weed seeds. Inputs to the seed bank are shown with black arrows and losses with white arrows. Figure Credit: Fabian Menalled, MSU Extension, Montana State University.

Maintaining excellent weed control for several consecutive seasons can eliminate a large majority of the weed seed bank, but a small percentage of viable, highly dormant seeds persist, which can be difficult to eliminate (Egley, 1986). Researchers are seeking more effective means to flush out these dormant seeds through multiple stimuli (Egley, 1986).

Weed species also differ in the seasonal timing of their germination and emergence. Germination of many species is governed by **growing degree–days (GDD)**—the summation of the number of degrees that each day's average temperature exceeds a base temperature. This concept is founded on the assumption that, below the base temperature, the organisms (in this case seeds) are quiescent, and that as "thermal time" accumulates above this temperature, their development proceeds. In addition, some newly shed weed seeds must first undergo a period of unfavorably cold or hot conditions before they can germinate in response to favorable temperatures. This initial, or primary, dormancy delays emergence until near the beginning of the next growing season—late spring for warm-season weeds (dormancy broken by cold period over winter), and fall for winter annual weeds (dormancy broken by hot period in summer)—when emerging weeds have the greatest likelihood of completing their life cycles and setting the next generation of seed.

The Iowa State University Cooperative Extension Service has evaluated seed germination response of common weeds of field corn in relation to GDD calculated on a base temperature of 48°F beginning in early spring, and categorized the weeds into germination groups (cited in Davis, 2004). For example, winter annuals like field horsetail and shepherd's purse germinate before any GDD accumulate in the spring; giant ragweed and common lambsquarters require fewer than 150 GDD and therefore emerge several weeks before corn planting; redroot pigweed, giant foxtail, and velvetleaf germinate at 150–300 GDD, close to corn planting time; whereas large crabgrass and fall panicum require over 350 GDD and usually emerge after the corn is up. A few species, such as giant ragweed, emerge only during a short (<3 week) interval, whereas others, such as pigweed and velvetleaf, continue to emerge for an extended period (>8 weeks). Knowing when the most abundant species in a particular field are likely to emerge can allow the farmer to adjust planting dates and cultivation schedules to the crop’s advantage.

Several factors other than mean daily soil temperature have a major impact on the timing of weed germination and emergence in the field. Adequate soil moisture is critical for germination, and good seed–soil contact is also important in facilitating the moisture uptake that is required to initiate the process. Thus more weeds may emerge from a firmed soil surface, such as occurs under planter press wheels, than from a loose, crumbly, or fluffy soil surface (Gallandt et al., 1999). For example, densities of common chickweed and common purslane in seeder tracks—in the crop rows—were roughly double those over the rest of the field, whereas annual grass weeds and yellow nutsedge did not show this pattern. (Caldwell and Mohler, 2001).

In addition, many weed seeds are also stimulated to germinate by light (even the very brief flash occasioned by daytime soil disturbance), fluctuations in temperature and moisture, or increases in oxygen or nitrate nitrogen (N) levels in the soil. Tillage, which exposes seeds to these stimuli, is therefore a critical determinant of seed germination. The timing of N fertilizer applications can also influence the number of weeds germinating. For example, many weed species can be stimulated by large increases in soluble N after incorporation of a legume cover crop, or inhibited by delayed applications of N fertilizer.

Shallow soil disturbance during periods of peak potential germination can be an effective tactic for debiting (drawing down) the weed seed bank (Egley, 1986). This phenomenon is exploited when timely cultivated fallow is used to reduce the weed seed bank, and in the establishment of a stale seedbed prior to planting. These tactics encourage the conditionally dormant portion of the seed bank to germinate so that the crop can be sown into a reduced initial weed population.

Weed seeds disperse both horizontally and vertically in the soil profile. While the horizontal distribution of weed seeds in the seed bank generally follow the direction of crop rows, type of tillage is the main factor determining the vertical distribution of weed seeds within the soil profile. In plowed fields, the majority of weed seeds are buried four to six inches below the surface (Cousens and Moss, 1990). Under reduced tillage systems such as chisel plowing, approximately 80 to 90 percent of the weed seeds are distributed in the top four inches. In no-till fields, the majority of weed seeds remain at or near the soil surface. Clements et al. (1996) have shown that soil texture may influence weed seed distribution in the soil profile under these different tillage systems (Fig. 2).

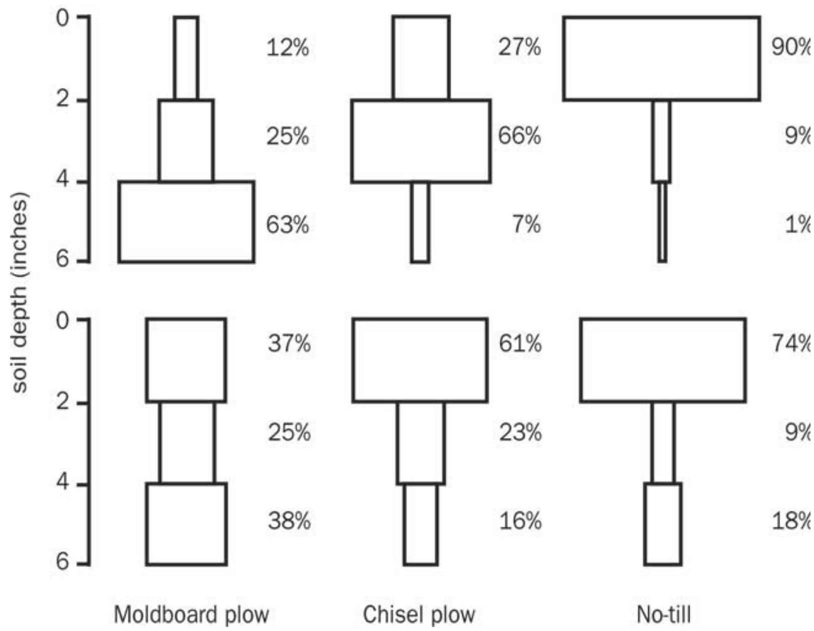

Figure 2. Vertical distribution of weed seeds in a loamy sand soil (top) and a silty loam soil (bottom). Figure credit: adapted from Clements et al. (1996) by Fabian Menalled, MSU Extension, Montana State University.

Understanding the impact of management practices on the vertical distribution of seeds is important because it can help us predict weed emergence patterns. For example, in most soils small-seeded weeds such as kochia, Canada thistle, and common lambsquarters germinate at very shallow depths (less than ½ inch). Large seeded weeds such as common sunflower have more seed reserves and may germinate from greater depths.

Thus, one strategy for managing the weed seed bank, especially for smaller-seeded weeds, is to maintain seeds at or near the soil surface. It is here that seeds experience the greatest exposure to environmental cues that will encourage germination—the most effective means of debiting the seed bank—as well as greater exposure to seed predators (see **Encouraging Weed Seed Predation and Decay**). Studies have confirmed that some weed seeds, including velvetleaf, morning glory, and pigweed, germinate in larger numbers in untilled than in tilled soil during the first year after seed shed (Egley and Williams, 1990). It may be tempting to use inversion tillage to place seeds below the depth from which they can emerge. This may be an effective strategy for species with short-lived seeds (see below), but it may simply protect longer-lived seeds from mortality factors like seed feeding animals and decomposer fungi, only to be returned to the soil surface by the next deep plowing event.

Factors Affecting Weed Seed Longevity

The number of viable seeds remaining from a given year's weed seed return declines over time as a result of germination (successful or fatal), predation, and decay. The percentage remaining declines in an approximately exponential manner, similar to the decay curve for a radioactive chemical element—the time for the number to decline by 50% is roughly the same, regardless of the initial num. The half-life of weed seeds varies widely among weed species; for example, hairy galinsoga and some annual grass weeds, such as foxtail species, last only one to a few years, whereas some curly dock and common lambsquarters seed can last over 50 years.

The actual seed longevity in the soil depends on an interaction of many factors, including intrinsic dormancy of the seed population, depth of seed burial, frequency of disturbance, environmental conditions (light, moisture, temperature), and biological processes such as predation, allelopathy, and microbial attack (Davis et al., 2005; Liebman et al., 2001). Understanding how management practices or soil conditions can modify the residence time of viable seeds can help producers minimize future weed problems. For example, seeds of 20 weed species that were mixed into the top 6 inches of soil persisted longer in untilled soil than in soil tilled four times annually (Mohler, 2001a), which likely reflects greater germination losses in the disturbed treatment. On the other hand, a single tillage can enhance the longevity of recently-shed weed seeds, because buried seeds are usually more persistent compared to those left at the surface where they are exposed to predators, certain pathogens, and wide fluctuations of temperature and moisture. However, soilborne pathogens may also contribute to attrition of buried seeds, even in large-seeded species like velvetleaf (Davis and Renner, 2008).

Although seed longevity of agricultural weeds is a cause for notoriety, and a proportion of the population may remain viable for several years or decades, most of the seeds of many weed species will either germinate or die shortly after being dispersed from the parent plant. The seeds of many grasses are particularly short lived. For example, in a field study conducted near Bozeman, MT, wild oat seeds were incorporated into the top four inches of a wheat–fallow field, and approximately 80 percent of them died during the first winter (Harbuck, 2007). It is important to note, however, that postdispersal survival varies widely among weed species.

Evaluating the Weed Seed Bank

One way to estimate a field's weed seed bank is to wait and see what weeds emerge during the first season. However, knowing something about seed bank content before the season starts can help the farmer prevent severe weed problems before they develop. Davis (2004) recommended the following simple procedure for scouting the weed seed bank:

> A little effort in understanding your weed seedbank [*sic*] can give you valuable information about what weeds to expect in a given growing season, weed density, and when most weed germination will take place. To get a weed preview, you can germinate weeds indoors as you're waiting to plant. For summer annual weeds, such as velvetleaf, foxtail, lambsquarters, and pigweed, March–April is a good time to sample weed seedbanks [*sic*] in the North Central region. Using a soil probe or a garden trowel, take 20 samples to a 2" depth in a 'W' pattern from the field you're interested in. Place the soil in a pie dish, put in a warm place (> 65 ° F) and keep moist. Within one to two weeks, you should have an idea of what weeds will be emerging in your field as the soil warms.
>
> ~ Davis, 2004

For a more representative sampling, collect sufficient soil samples to fill several pie dishes, or a seedling flat. The larger the sample, the more closely the observed weed emergence will reflect field populations.

Keep in mind that this method is not likely to reveal all the species present in a field. However, in combination with field observations on seasonal patterns of weed emergence, greenhouse weed emergence tests can help anticipate when control tactics are likely to be needed in the coming season, and to begin developing a seed bank management strategy.

Some Weed Seed Bank Management Practices

Use these strategies to minimize annual inputs (deposits) to the weed seed bank:

- Kill weeds before they set seed—before flowering to be safe, because some weeds (such as hairy galinsoga) can mature seeds from flowers that are pollinated before the weeds are pulled or severed . If in doubt, attempt to thresh the seeds from the fruits or flowers of flowering weeds; dough-consistency and firm seeds can be considered mature and should be removed from the field if possible.
- Control creeping perennial weeds before they can form new rhizomes, tubers, or other propagules.
- Keep crops ahead of the weeds—small weeds overshadowed by a good crop canopy may have less than 1% of the seed forming capacity of vigorous individuals growing in full sun.
- Walk fields to remove large weed escapes before they flower. Getting the largest 10% of individuals can reduce seed production by 90% or better.
- Mow field margins to minimize seed set by weed species that have the potential to invade fields. (Balance this with the potential role of field margins as beneficial insect habitat).
- Mow or graze fields promptly after harvest to interrupt weed seed production.
- Utilize good sanitation practices to prevent introduction of new weed species into the field, and remove new invaders before they propagate.

Another measure that can help contain seed bank populations is to increase the diversity of crop rotations. Although data on the effects of crop rotations on weed seed banks in organic systems have not been consistent, there is some evidence suggesting that more diverse rotations, especially those that include one or more years in red clover, alfalfa, or other perennial sod crops, can help reduce seed inputs from velvetleaf and other annual weeds, and promote seed bank declines through seed predation and decay (Davis et al., 2005; Teasdale et al., 2004; Westerman et al., 2005).

Use these strategies to maximize losses (withdrawals) from the weed seed bank:

- Till or cultivate to stimulate weed seed germination at a time when the seedlings can be easily knocked out by additional cultivation or flaming (stale seedbed), or will be freeze-killed before they can reproduce. Rolling after tillage can further enhance germination by improving seed–soil contact.
- If practical, time this tillage or cultivation to take place when seeds of the major weeds present are least dormant, and/or during the season of the weeds' peak emergence, in order to maximize the seed bank withdrawal.
- Time crop planting to facilitate destruction of flushes of weed seedling emergence. For example, if the major weeds in a given field are known to reach their peak emergence in mid May, delay corn planting until end of May to allow time to remove this flush prior to planting.
- Maintain habitat for weed seed predators—vegetation or mulch cover—in at least part of the field for as much of the year as practical.
- Reduce or avoid tillage during critical times for weed seed predator activity. If a significant weed seed rain has occurred, leave weed seeds at the surface for a period of time before tilling to maximize weed seed predation.

Because soil microorganisms can play a role in weed seed decay, maintaining a high level of soil biological activity through good organic soil management might be expected to shorten the half-life of weed seed banks. In addition, incorporation of a succulent legume or other cover crop may either stimulate weed seed germination by enhancing soil nitrate N levels, or promote weed seed or seedling decay as a result of the “feeding frenzy” of soil microorganisms on the green manure residues. However, the potential of these practices as weed seed bank management tools requires verification through further research.

While it is sometimes advantageous to cause weed seeds to germinate, it is important at other times to keep them quiescent long enough for the crop to get well established. Several practices can help reduce the number of weeds emerging in the crop.

- Cultivate at night or with light shields over the cultivation implement to minimize the light stimulus to weed seeds.
- Leave a loose soil surface after planting or cultivation to reduce seed–soil contact for near-surface weed seeds, thereby deterring germination. If practical, cover newly seeded rows with loose soil to reduce within-row weed emergence.
- Minimize soil disturbance at or near the time of planting. Do major tillage in fall or very early spring several weeks before planting. Use flame or very shallow cultivation to prepare the seedbed.
- Avoid practices that result in early pulses of nitrogen that may stimulate weed emergence. Use split N fertilizer applications and slow releasing forms of N, such as compost and legume–grass cover crop mixtures) to make N availability patterns over the season match N needs of the crop rather than the weeds.
- Avoid planting crops in fields with heavy populations of weeds with similar life cycles. For example, fields dominated by late emerging summer annual weeds might best be planted in early crops like peas.
- Time crop planting to take place well before the most abundant weed species in the field are expected to emerge.
- Time crop planting to take place after the expected major weed seedling flushes, and remove the latter by shallow cultivation or flame weeding.
- Invert the soil to a depth from which weed seeds cannot emerge (most effective for weeds with small, short-lived seeds).

Incorporated green manures or surface residues of cover crops can reduce the establishment of small-seeded weeds through allelopathy and/or physical hindrance. Thus, these practices can provide a measure of selective weed control for transplanted or large-seeded crops, which are tolerant to the stresses imposed by cover crop residues. This selectivity does not apply to small-seeded, direct sown vegetables like carrots and salad greens, which are at least as sensitive to these cover crop effects as small-seeded weeds.

Challenge of Weed Seed Bank Diversity

Remember that none of these strategies can be expected to eliminate the weed seed bank, and also that you may need to change seed bank management strategy as the seed bank itself changes. The reason the weed seed bank is so difficult to manage is because it contains not only many seeds, but many different kinds of seeds, with typically 20 to 50 different weed species in a single field. In other words, the grower may have to deal with 20 to 50 different plant survival strategies! Thus, there will almost always be some weeds that tolerate, or even thrive on, whatever combination of seed bank management strategies the farmer adopts.

For example, some but not all weed species have light-responsive seeds, and dark cultivation reduces emergence only in the light responders. Similarly, careful nitrogen (N) management can reduce problems with nitrate responders but have no effect on nonresponders and could even favor a weed that is well adapted to low levels of soluble N. The best approach to weed seed bank management is to design your strategy around the four or five most serious weeds present, then monitor changes in the weed flora over time, noting what new weed species emerge as the original target weed species decline. Then change your seed bank management strategy accordingly. Plan on making such adjustments every few years, and if possible, keep a sense of curiosity and humor about the weeds!

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables**. For more on managing the weed seed bank, see:

- **Manipulating Weed Seed Banks to Promote their Decline**
- **Keeping New Weedy Invaders Out of the Field**
- **Promoting Weed Seed Predation and Decay**

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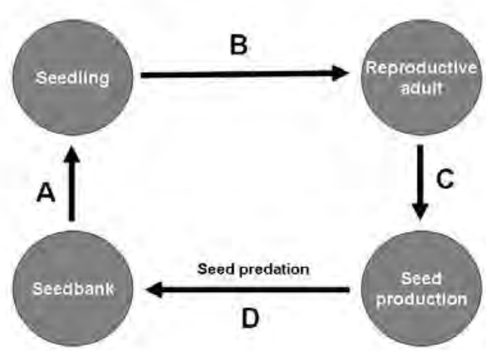
University Extension

Weed Science
Department of Agronomy

Weed Seed Predation in Agricultural Fields

Weed communities in agronomic fields are dominated by annual species. Summer annuals initiate growth each spring from seeds found in the upper soil profile (Figure 1). In most fields, a small percentage of the emerging plants survive and contribute new seeds to the soil seedbank. Historically, most research of the annual weed life cycle has focused on seed dormancy and emergence (A), effect of control tactics on weed survival (B), and weed seed production (C). The fate of seeds between the time of maturation on the plant and entering the seedbank (D) has largely been ignored. However, current research at Iowa State University and other organizations has shown that significant seed losses routinely occur in agronomic fields, and these losses may influence the effectiveness of weed management programs. This article will provide a brief summary of some of the current research in this area and the potential importance of seed predation to weed management.

Figure 1. Annual Life Cycle

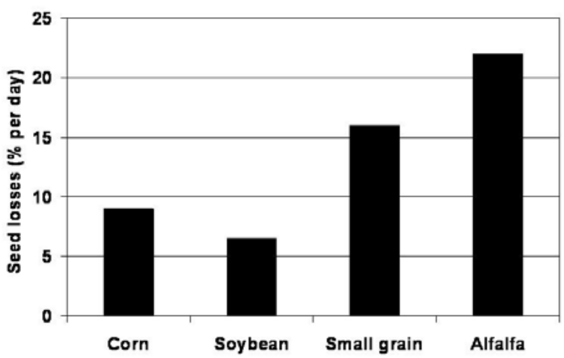


Plant seeds are storage organs for high energy compounds that supply plant embryos the resources needed to germinate and develop into seedlings. These energy reserves are an excellent food source for a variety of animals that live in or near agricultural fields, including ground beetles (carabid beetles), crickets, mice and others. Estimates of cumulative seed losses due to seed predators have ranged from 20% for barnyardgrass and lambsquarter in a chisel plow system (Cromar et al. 1999) to 88% for giant ragweed in no-tillage (Harrison et al. 2003).

Prairie deer mouse – a common seed predator.

A common method of measuring seed predation involves lightly attaching seeds to sandpaper or a similar material and placing the seed cards in the field. After a few days the card is retrieved and the percentage of seeds removed is determined (Westerman et al. 2005). Averaged over 12 sampling periods from May through November, seed losses ranged from 7 to 22% per day depending on crop in a study conducted near Boone, IA (Figure 2). The higher predation rates in small grain and alfalfa compared to corn and soybean may be due to differences in crop canopy development. The rate of seed predation typically increases as a crop canopy develops within a field. Corn and soybean canopies provide little protection for predators early in the growing season compared to small grain or alfalfa, and thus predators may seek other habitats when little canopy is present. Later in the season, predator activity is typically similar in corn and soybeans as in other field crops.

Figure 2. Daily losses to seed predation in different crops.



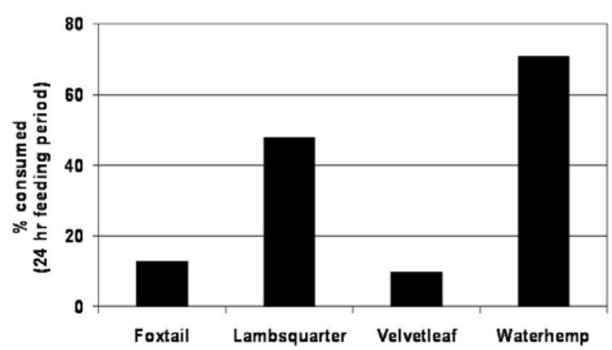
Westerman et al. 2005. Weed Sci.

Insect predators (field crickets, ground beetles, etc.) are active during the growing season when temperatures are favorable for cold-blooded species, whereas field mice are active year round. Seed predators have a remarkable ability to locate seeds on the soil surface; however, once seeds move into the soil profile the threat of predation is greatly reduced. The highest rates of seed predation likely occur in late summer and early fall when weed seeds are shed from plants onto the soil surface. Tillage buries the majority of seeds at depths where predation is minimal. Avoiding or delaying fall tillage following harvest should increase seed losses due to predation. Seeds can also enter the profile due to the impact of rain droplets, by falling into cracks, or due to freezing/thawing cycles during the winter. Ongoing research at ISU is evaluating the fate of seeds on the soil surface and how long they remain available to predators.

Field crickets on seed card.

The preference of predators for different species of weed seeds in the field is poorly understood. When given a choice, seed predators often will feed preferentially on one species over another (van der Laat et al. 2006; Figure 3). A common question is whether seed predators pose a threat to crop seed. Seed size and depth of planting minimize risks of corn and soybean seed losses to predators. Small-seeded legumes and grasses are at greater risk for predation losses, but proper planting where the majority of seed are placed under the soil surface should minimize losses.

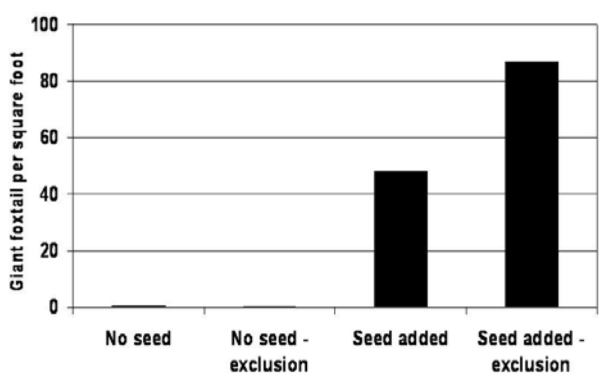
Figure 3. Feeding preference of field crickets for four weed seeds.



van der Laat et al. 2006.

Significant numbers of weed seeds are consumed by predators in agronomic fields, but the full impact of seed predation on weed densities and weed management is poorly documented. Clearly, destruction of a significant percentage of the weed seeds produced in a field will impact the following year's weed density. The impact of giant foxtail seed rain and seed predation on giant foxtail densities was evaluated near Boone, IA (Figure 4). Giant foxtail seed (750/ft^2) were spread on the soil surface in standing corn in late September 2004. The field was planted to no-till soybean in 2005 and foxtail emergence monitored throughout the season. The experimental area had a history of good weed control, thus foxtail densities were very low (< 1/ft^2) in plots where no seed was added the previous fall. Excluding predators by placing mesh screens over freshly spread seed resulted in nearly a 50% increase in giant foxtail densities. That is, plots protected from seed predators had higher weed densities than did plots to which seed predators had access.

Figure 4. Effect of predator exclusion on giant foxtail populations.



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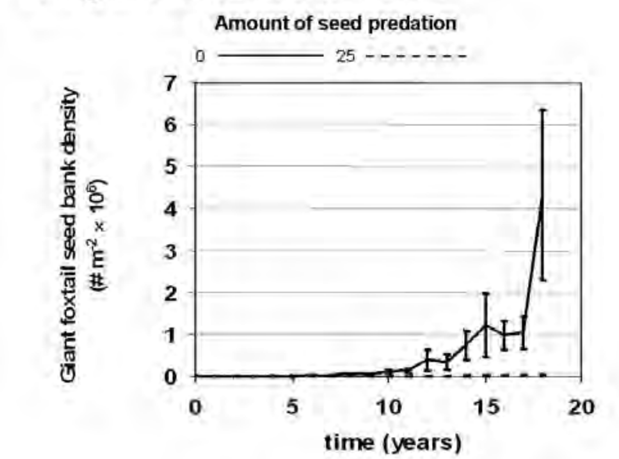
Modeling efforts at ISU have shown that seed predation can significantly affect long-term weed population dynamics within agricultural fields. For example, in a 4-year crop rotation (corn/soybean/small grain+alfalfa/alfalfa) the seed bank of giant foxtail rapidly increased from 2000 seed/m^2 to 4.3 million seed/m^2 over an 18 year simulation period in the absence of predation (Figure 5). However, allowing for 25% seed predation resulted in a static seed bank, whereas any seed predation in access of 25% resulted in a decline in the seed bank density. The diverse rotation required 80% less herbicide than a conventionally managed corn-soybean rotation.

Figure 5. Effect of seed predation on giant foxtail seed bank.



The value of intercepting weed seed before they enter the seed bank is somewhat of a forgotten control tactic. In the 1930's and 40's, combines were commonly equipped with a weed seed collector that separated and collected weed seed from chaff as the crop was harvested. When modern herbicides were introduced in the 1950's, it was considered less expensive and more convenient to control weeds with chemicals, and these accessories quickly disappeared from combines. In Australia, seed collectors are again being used on combines due to widespread herbicide resistance and the loss of effective herbicides. Rigid ryegrass infestations have been reduced by as much as 70% through use of weed seed collectors during harvest (Gill, 1995). The effectiveness of weed seed collectors varies among weed species depending on timing of seed shed. Weed species that drop the majority of their seed prior to crop harvest would not be impacted significantly by use of weed seed collectors.

Weed seeds are an important food source for a variety of organisms that live within or adjacent to agricultural fields. It is clear that seed predation is an important form of biological control that influences weed communities within agricultural fields. Yet to be defined is how cropping systems can be manipulated to enhance the activity of seed predators and maximize their benefit, therefore allowing reductions in other more disruptive control tactics.

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04 Don't plant weeds with your winter rye: Weed seed contamination can spell disaster

posted on August 04, 2010 12:58

Daniel Brainard and D. Corey Noyes, Horticulture

As cash crops come out of the ground and you think about planting cover crops like winter rye, be careful to check the seed for weed seed contamination. Weed seeds can be tiny and difficult to see, but surprisingly numerous in cover crops. For example, a sample pulled from a bag of winter rye in Michigan last week had 95 weed seeds per pound (figure 1). If you planted this rye at 2 bu/A, that would represent over 10,000 weed seeds.

Among the weed species present in this sample were hairy vetch, smartweed (lady's-thumb) and corn cockle (Figure 2). These and other weeds sometimes found in cover crop seed can cause problems in subsequent vegetable crops. For example, smartweed is a summer annual that can be difficult to manage in many vegetable crops including broccoli and snap beans. The moral of the story is either pay extra for certified seed, or take a close look at your cover crop seed before purchasing to avoid spreading problems across your fields.

The following is an excellent website for identifying weed seeds: http://www.oardc.ohio-state.edu/seedid/

Figure 1. Weed seeds found in winter rye sample (left) (seeds at approximately actual size on right).

Figure 2. Close-up of weed seeds from rye sample. Corn cockle or close relative (left) and smartweed or close relative (right).

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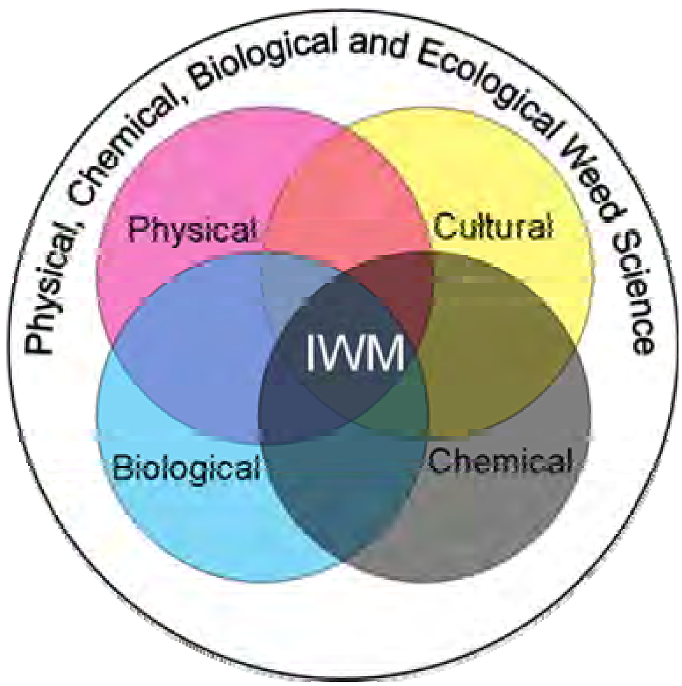
Stale Seedbed

Information: Integrated Weed Management

Introduction- Integrated Weed Management

Until the 1940s, when the use of chemical herbicides first became widespread, physical, cultural and biological weed management were the only means of controlling weeds. The ability of the selective and systemic herbicides to kill weeds but leave crops unharmed or to kill even large plants, even those that could regenerate from underground structures, appeared almost magic to the farmers of the time. These astounding abilities lead to a widespread belief that herbicides would solve the 'problem' of weeds once and for ever. However, after over 50 years of widespread herbicide use it is clear that the 'war on weeds' is far from over, and that if anything, sole reliance on herbicides is a loosing strategy. Herbicide resistant weeds are an increasing problem and the negative side effects of herbicides are a growing concern. This has seen a resurgence of interest in the 'old guard' of physical, cultural and biological weed management, which, combined with the judicious use of herbicides and based on a thorough understanding based in weed science is called Integrated Weed Management or IWM.



The four complementary aspects of Integrated Weed Management (IWM) built on the solid foundation of weed science.

The common conception of physical weeding is hoeing weeds from a crop. However, from an IWM perspective hoeing is just the 'icing on the cake' or if things are going badly 'the ambulance at the bottom of the cliff' (remembering physical weeding is just one part of an integrated weed management system). Relying on in-crop weeding as the sole or even main means of weed management is likely to result in weed management becoming impossible after just a few years. Based on scientific research and our own extensive practical experience PhysicalWeeding believes that one of the most important aspects of physical weed management in annual crops, especially vegetable and similar lower competitive crops, are false and stale seedbeds. These are not new ideas, and were widely practiced before the advent of herbicides, but during the last fifty years they have slipped from living memory. These terms are also often used interchangeably, however, here they are considered to be two distinct but related approaches.

False and stale seedbeds

The false and stale seedbed techniques are based on three 'golden rules':

- Tillage (cultivation) promotes weed seed germination;
- Only 5 to 10% of weed seeds in the soil are non-dormant and able germinate at any given time, but those that can, mostly germinate quickly;
- The vast majority of weeds only emerge from seeds in the top 5cm / 2" of soil, and most typically only emerge in significant numbers from the top 2.5cm / 1" of the soil.

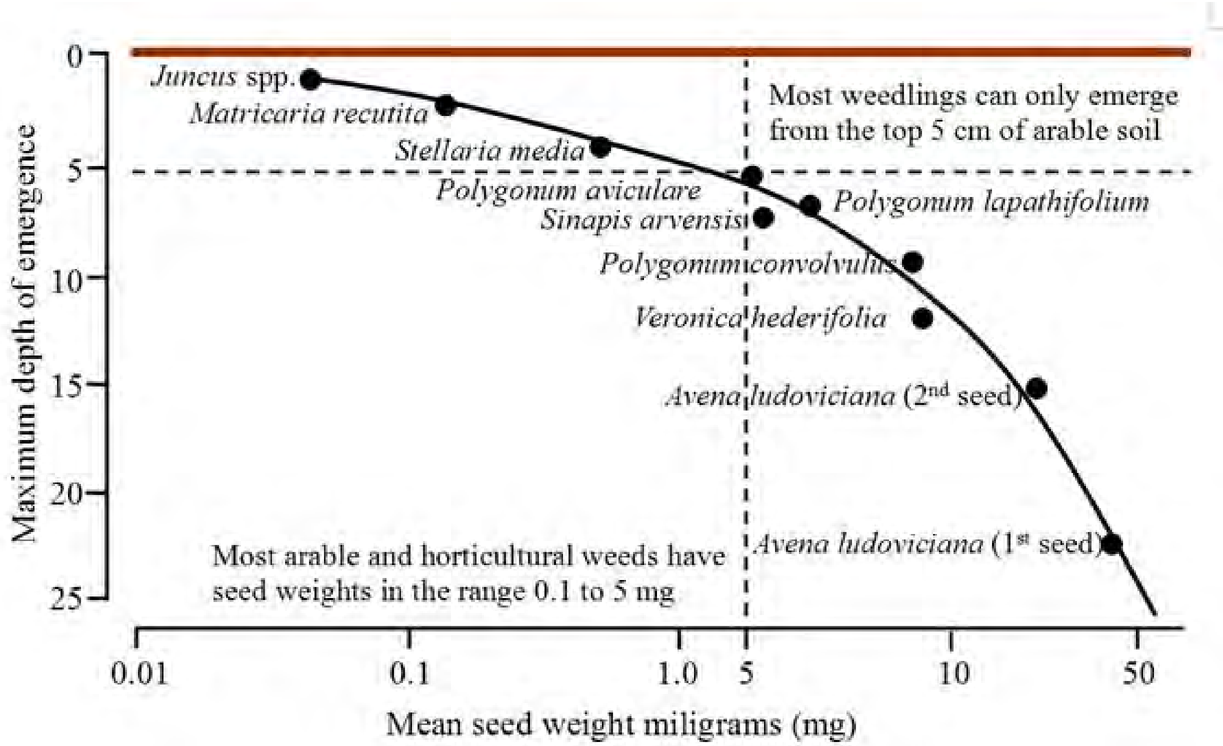
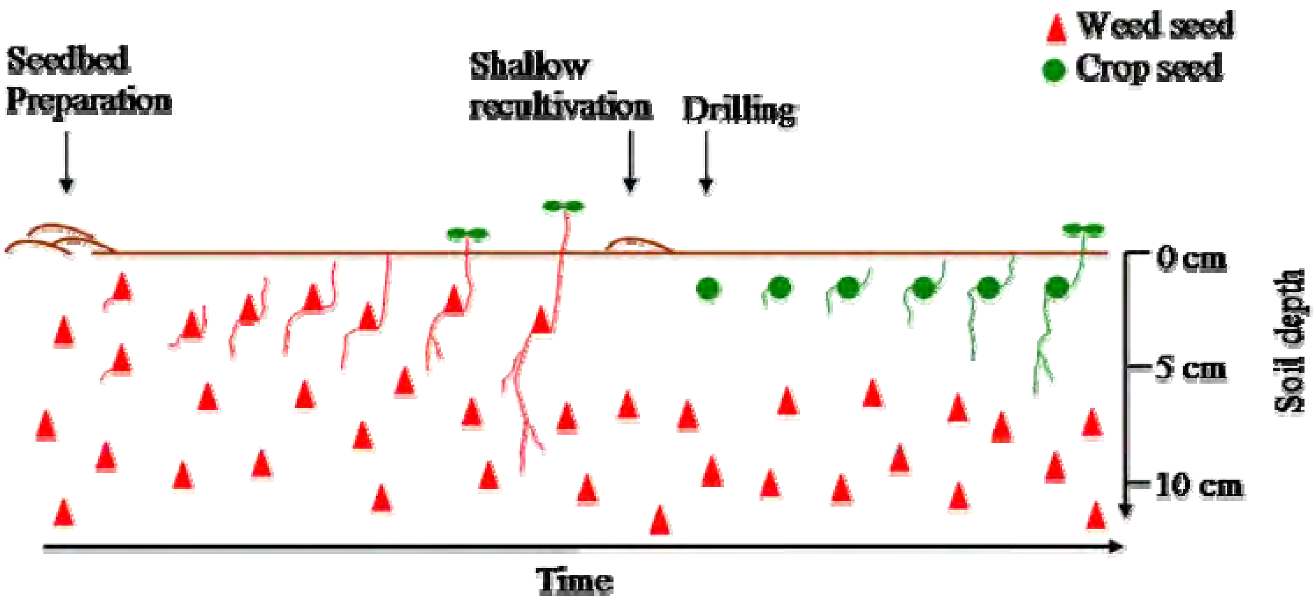


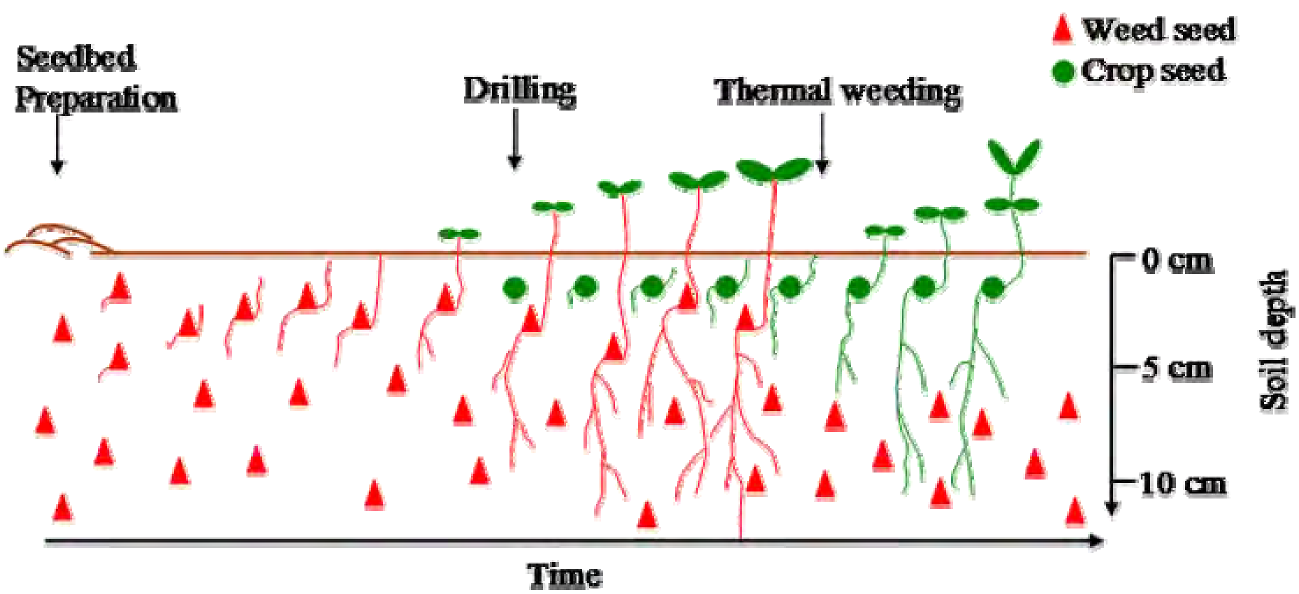
Diagram of the maximum emergence depth of a range of weed species according to seed weight (size). (Based on Roberts, H. A. (Ed.). (1982). Weed Control Handbook (7th ed.). Oxford: Blackwell Scientific Publications.)

This knowledge can be used to eliminate many, if not most, of the weeds that would normally infest an annual crop at establishment. This is done by creating a planting tilth but then delaying planting so that the weeds germinate and/or emerge before the crop and are then killed either by further tillage, thermal weeding or herbicides. The former is called a false seedbed, as the original seedbed is not the true final seedbed, i.e., it's a false seedbed and the latter a stale seedbed as the first seedbed has aged, or become 'stale', by the time the crop is planted and/or emerged.

The two diagrams below show the details of how false and stale seedbeds work.



False seed bed: A seedbed is prepared, weed seeds in the top 5 cm / 2" of soil germinate and then emerge, the soil is then re-tilled (cultivated) with the minimum disturbance necessary to kill weed seedlings, the crop is then sown, germinates and emerges from mostly weed free soil.



Stale seed bed: Final seedbed is prepared, weed seeds in the top 5 cm / 2" of soil germinate, crop is sown, weed seedlings emerge, immediately prior to crop emergence weed seedlings are killed by a thermal weeder, crop emerges from weed free soil.

Each of these techniques has a component that is critical for its success. For false seedbeds re-tillage must involve the minimum depth of tillage necessary to kill all weedlings, and must be less than 5cm / 2” otherwise non-dormant weed seeds could be brought up from lower soil levels which then germinate in the crop. For stale seedbeds the thermal weeder should be used as close to crop emergence as possible to get the greatest benefit which means it needs to be both fast and effective as the time-window for successful treatment can be very short, e.g., hours.

However, until now there were no tillage machines on the market that were specifically designed to achieve optimum false seed retillage, and many existing thermal weeders are too inefficient, in terms of work rates and/or fuel consumption. PhysicalWeeding is your one-stop solution for optimal false seedbed tillers, flame weeders and steam weeders.

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Manipulating Weed Seed Banks to Promote their Decline

Last Updated: March 23, 2010

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Introduction

The weed seed bank present at the beginning of a cropping cycle represents the *potential* for weeds to reduce crop yields, but it does not predict that weeds *will* do so. Organic growers can employ several strategies to reduce the potential of existing weed seed populations to inflict economic damage. Weed seed banks can be manipulated by:

- Tricking weed seeds into germinating when they can be easily killed
- Conditioning weed seeds or modifying their immediate environment so that they become less likely to germinate during critical phases of crop establishment and production
- Concentrating weed seeds at a position within the soil profile from which they cannot easily emerge, or at which they are most subject to attrition
- Moving germinable weed seeds away from the crop in space (e.g., ridge tillage) or in time (planting date before or after the weeds' peak emergence season)

Choosing the most effective strategies for a particular field requires sufficient knowledge of the field's weed seed bank, including the major weed species represented and perhaps age and vertical distribution of seeds in the soil profile, as well as a rough estimate of total population density. Weed species differ widely in seed dormancy and longevity, season in which they emerge, depth from which they can emerge, and seed responsiveness to light and other stimuli (Table 1). These characteristics can help the farmer select the best strategies for managing a particular weed seed bank.

Tricking the Weed Seeds: Stale Seedbed and False Seedbed

Many weed seeds, especially smaller-seeded annual broadleaf species, germinate in response to stimuli that indicate that the soil surface has been disturbed and cleared of competing vegetation. Light is the most common germination trigger, though many seeds also respond to temperature and moisture fluctuations, increased aeration, and increased release of nitrate and other soluble nutrients that occur in tilled soil (Table 1). Many weed species also tend to germinate during specific times of year after a certain amount of soil warming. For these weeds, the time of emergence during spring can be approximately predicted by the accumulated **growing degree–days (GDD)**, a summation of the number of degrees that daily average temperatures exceed a base temperature (Table 1).

Table 1. Weed seed germination and emergence characteristics of several weeds of row crops in the north-central United States[1].

Weed Species	Season of Emergence[2]	Emergence Period (wk)	Emergence Depth[3]	Half-life[4] (yr)	Germination Stimuli
Horseweed	Fall/early spring				L
Shepherds-purse	Fall/early spring	S		2.8	C, L, N, T±
Field pennycress	Fall/early spring		M	5.7	L, T±, A
Giant ragweed	GDD <150	2-3		0.3	
Common lambsquarters	GDD <150	3-7	S	7.6	L, T±, N
PA smartweed	GDD <150	3-7		4.0	
Annual sunflower	GDD <150	3-7		0.3	
Redroot pigweed	GDD 150-300	8-10	S	2.2	L, H, T±, N
Common ragweed	GDD 150-300	3-7	M	1.4	C, L, T±
Velvetleaf	GDD 150-300	8-10	D	2.3	A
Giant foxtail	GDD 150-300	8-10		0.8	
Yellow foxtail	GDD 250-400	3-7	D	4.5	C, N
Black nightshade	GDD 250-400	3-7	M-D	L, T±, N	
Common cocklebur	GDD 250-400	3-7	D	5.6	C, T±, (D)
Wild proso millet	GDD 250-400	3-7			
Large crabgrass	GDD >350	3-7	M	1.2	C, (D)
Fall panicum	GDD >350	3-7			T±
Waterhemp	GDD >350	8-10		2.4	

Morningglory	GDD>350	8-10			

[1] The information in this table is based on Tables 1 and 3 in Davis (2004), and an extensive literature review of weed seed ecology research by Charles A. Mohler.
[2] GDD = growing degree-days F (base temperature 48°F). GDD<150 – emerge several weeks before corn planting in the North Central region; GDD 150-300 – emerge shortly before or during corn planting; GDD 250-400 – emerge near the end of corn planting; GDD>350 – emerge after corn emergence.
[3] S = shallow, most seeds emerge from surface or top 0.5 in of soil profile; M = medium, most seeds emerge from top inch; D = deep, most seeds emerge from top 2 inches, and a few can emerge from greater depth.
[4] About 6 to 7 half lives required to eliminate 99% of seed from the weed seedbank.
[5] A = aeration; C = chilling period; H = high soil temperature; L = light; (D) = *not* responsive to light; N = nitrate; T± = fluctuating soil temperatures.

When several of these conditions occur together—for example, a tillage operation at the weed's normal time of emergence that creates a light flash and promotes nitrogen mineralization—a high proportion of weed seeds may germinate provided that soil moisture and seed–soil contact are adequate. If the farmer prepares a seedbed and sows a vegetable crop at this time, weed problems will occur. However, if the farmer delays planting until several weeks after seedbed preparation, one or more flushes of weeds can be eliminated by shallow cultivation or flame weeding before planting. If this is done during the weeds' peak season of emergence, much of the population of readily-germinable weed seeds can be depleted. Two forms of this strategy are called stale seedbed and false seedbed.

In the **stale seedbed** approach, the soil is tilled to prepare for seeding the crop, then planting is delayed for two or three weeks to allow a flush of weeds to emerge. Just before sowing the crop, emerged weeds are killed with no or minimal soil disturbance. Organic farmers can kill weeds by flaming or cultivating as shallowly as practical, though *any* cultivation will stimulate some additional weeds to germinate with the crop. Conventional farmers normally use herbicides at the end of the stale seedbed period, an option that may become open to organic producers in the future with the development of natural-product postemergence herbicides that are economically viable at the field scale.

In the **false seedbed** approach, weeds emerging in response to tillage are killed by two or more additional shallow cultivations at weekly intervals. The crop is planted immediately after the final cultivation. Because small weed seeds germinate better when the soil is firmed to enhance seed–soil contact, rolling is recommended after all except the final cultivation.

Ideally, the final cultivation just before crop planting is done as shallowly as practical to avoid stimulating further weed seed germination, and leaves the soil surface loose and open, forming a dry, crumbly layer from which weed seeds are less able to take up moisture and germinate. Note that good soil tilth promoted by high organic matter and biological activity is essential for these tactics to work effectively. Light duty implements like flexible tine weeders cannot effectively penetrate crusty, cloddy or compacted soils, and stale seedbed can fail to yield weed management benefits in these conditions (Caldwell and Mohler, 2001).

Organic farmers successfully use these approaches to reduce weed pressure in subsequent crops, sometimes realizing weed control commensurate with conventional herbicide applications. Possible drawbacks include yield loss due to delay in planting, increased risk of soil erosion and crusting during the cultivated fallow period, and the risk that dry conditions might inhibit the desired weed seed germination. Another limitation of stale seedbeds is that planting or transplanting equipment can disturb the soil sufficiently to stimulate weed emergence in the crop row (Caldwell and Mohler, 2001). Researchers are now working to develop **punch planters**, which plant crops with minimal soil disturbance (Rasmussen, 2003).

If the weed seed bank includes weeds that generally emerge after the stale or false seedbed period, the practice may not reduce weed pressure, but only change weed species composition. For example these techniques may work well for soybean in the north-central and northeastern states if the main weeds are common lambsquarters, Pennsylvania smartweed, ragweed, and others that normally emerge before soybean planting. However, if the dominant weeds include later-emerging species like redroot pigweed, common cocklebur, and large crabgrass, a false seedbed would either miss these weeds or entail an unacceptable delay in crop planting. Stale and false seedbed may be especially well suited for late plantings of vegetable crops like lettuce, snap bean, or cucumber, for which sufficient time is available to deplete weed seed populations in the germination zone before vegetable planting. In the southern states, carrots, beets, and some other root crops can be planted in the latter half of July, which allows time for several weeks' cultivated fallow during the peak emergence period of many weeds.

Stale and false seedbed practices require favorable soil temperature and adequate soil moisture as well as sufficient time to obtain maximum weed emergence prior to crop planting. If soils are dry, some growers irrigate the newly-prepared seed bed to encourage weed emergence. In organic systems that utilize floating row covers for season extension or pest control, placing the row cover over the seedbed at the beginning of the fallow period can accelerate weed emergence by increasing soil temperature and moisture, and thereby enhance efficacy of the stale seedbed (Brainard et al., 2007). This practice reduces the need for removal of row cover for weed management following crop planting, and allows more timely planting of crops.

Certain summer annual weeds that have a long period of germination, or little or no seed dormancy, can be tricked into emerging late enough in the season that fall frosts or fall tillage will kill them before they can set seed. For example, if the final cultivation in late snap beans or fall broccoli stimulates emergence of morningglories, pigweeds, or foxtails, the weeds will not much affect crop yield, and the first frost may turn them into harmless organic matter before they flower. The short-lived, nondormant seeds of galinsoga can be triggered to germinate quite close to the fall frost date, for example during seedbed preparation for a fall cover crop. However, since the timing of frost is unpredictable, and many summer annuals produce seeds very rapidly under the short days of fall (as little as 25–30 days after emergence for galinsoga), this strategy entails risks, and may need to be supplemented by subsequent cultivation or manual weeding if frost is late. Prompt tillage or mowing after harvest of warm season crops like snap bean can prevent weed seed set if frost does not do the job.

Depleting the Seed Bank by Stimulating Germination

Theoretically, one should be able to deplete the soil's weed seed bank through repeated cultivation or other tactics that provide seed germination stimuli, combined with stringent year-round weed control that prevents weeds from setting seeds or otherwise reproducing. Timely cultivation combined with other measures to eliminate all weed seed set can draw most weed seed banks down to perhaps 5–10% of their initial population densities within several years; however the remaining seeds can be much more difficult to eliminate through such tactics (Egley, 1986). In some cases, the seeds are hard—they do not imbibe moisture even at high soil moisture content; in others they are in a state of deep dormancy that requires multiple environmental cues to break. Critical factors may include any or most of the following:

- Seasonal changes or daily fluctuations in soil temperature and moisture
- Light—presence or absence, and quality (full spectrum daylight or filtered through green foliage)
- Concentrations of nitrate and nitrite in the soil

- Concentrations of oxygen, carbon dioxide, and ethylene (C_2H_4) in the soil
- Presence or absence of specific germination stimulants or inhibitors released into the soil by plant roots or plant residues

Multiple stimuli can break the dormancy of at least some seeds in the more persistent weed seed bank, and researchers continue to explore means by which these can be effectively delivered in the field to lower weed seed banks further (Egley, 1986). Whereas some of the methods investigated are not appropriate for organic systems (for example, applications of soluble N fertilizers or the synthetic ethylene-generating compound ethephon), other strategies may emerge that utilize organic soil management practices to provide multiple seed germination stimuli.

Conditioning Weed Seeds: Putting Them to Sleep

A different strategy is to avoid soil disturbance and other weed seed germination stimuli before and during spring planting. Keeping weed seeds dormant until the crop is well established can substantially reduce potential weed competition. This is a major objective in the no-till cover crop management and vegetable planting systems that some organic farmers and researchers are developing, in which winter annual cover crops are grown to maturity (heading in grasses, flowering in legumes and other broadleaf crops) then rolled or mowed to create an *in situ* mulch.

However, no-till can be challenging and risky for organic growers, and other practices have been proposed for keeping weed seeds dormant during crop establishment. While some farmers utilize cultivated fallow in spring, others do primary tillage in fall and avoid or minimize soil disturbance in spring, utilizing a flame weeder to kill emerging seedlings while letting dormant weed seeds remain dormant (Davis, 2004). Many European growers believe that tilling their soil at night in late fall can condition the weed seed bank to reduce weed emergence in the following spring. Compared to daytime tillage, lightless tillage can reduce emergence of light-sensitive species like common lambsquarters, pigweeds, and barnyard grass by 50% or more, although results have not always been consistent (Buhler, 1997; Scopel et al., 1994). Since lightless tillage is effective primarily against small seeded broadleaf weeds (Buhler, 1997), continued use of night cultivation may select for species shifts that reduce its effectiveness over time (Dyer, 1995).

A dense, shading plant canopy can also deepen the dormancy of some weed seeds. The dim green light under such a canopy can actually be more effective than continuous darkness in inhibiting the germination of light-responsive seeds (Mohler, 2001a). Reduced weed emergence has been observed in the season *after* a dense-canopy crop such as a cereal grain/clover intercrop, or August-planted forage radish. Martens and Martens (2008) suggested that the light quality under such foliage may have rendered weed seeds more dormant. Dense crop canopies may also reduce subsequent weed emergence by reducing seed production or increasing seed mortality. For example, dense crop or cover crop canopies can provide favorable habitat for seed predators, resulting in reductions in the seed bank and subsequent weed emergence (Davis and Liebman, 2003).

This dormancy strategy works best for annual weeds whose seeds often show conditional, light-mediated dormancy. Some larger-seeded weeds—and especially the vegetative propagules of wandering perennial weeds like yellow nutsedge and Bermuda grass—may be difficult or impossible to condition for delayed emergence.

Since soluble N can stimulate germination of seeds of many weeds including pigweed and lambsquarters (Table 1), manipulation of soil fertility has been extensively explored as a tool for reducing weed density (Dyer, 1995). Practices that avoid large pulses of soluble N early in crop development, such as delayed or split

N applications, or use of slow-releasing N sources such as mature compost, can delay weed emergence and reduce weed density in the crop. Conversely, incorporation of leguminous cover crops or applications of materials that release N rapidly, such as chicken manure, can promote weed emergence and growth. For example, ammonium released from decomposing hairy vetch can stimulate germination of smooth pigweed (Teasdale and Pillai, 2006). Mixing such legumes with grasses can reduce the concentration of soluble N released after incorporation and may be beneficial for weed management.

The effects of N fertilization on weed emergence are variable, owing in part to complex interactions between N and other factors such as ethylene concentration in soil, light, and genetic differences in responsiveness both between and within weed species (Dyer, 1995; Brainard et al., 2006). Nonetheless, practices that improve the synchrony of crop N demand and N supply not only reduce the risk of N losses but may aid weed management by reducing weed emergence during crop establishment.

Seeds require adequate seed–soil contact in order to take up the moisture needed to initiate germination. For small seeds such as those of lambsquarters, galinsoga, or Canada thistle, a fine tilth and firmed soil surface optimizes seed soil contact and promotes germination, whereas a coarse, loose seedbed can significantly reduce their germination. This is why higher weed densities sometimes occur within rows of crops seeded by mechanical planters with press wheels (Caldwell and Mohler, 2001), and is one of the mechanisms by which incorporated cover crop residues can reduce weed emergence (Gallandt, 2006). Gallandt et al. (1999) further suggest that moving loose soil over planting rows after mechanical seeding can reduce within-row populations of small-seeded weeds.

Positioning Weed Seeds in the Soil Profile

Is it better to leave recently-shed weed seeds on the soil surface, or to plow them under? The answer: “It depends.” Burying the short-lived, small, nondormant seeds of weeds such as galinsoga and kochia to a depth of three or four inches can virtually eliminate viable seed within a year or so after it was shed (Mohler, pers. observation; Schwinghamer and van Acker, 2008). Longer-lived seeds like pigweeds, lambsquarters, and velvetleaf, however, may remain viable and dormant at this depth for several years, during which additional tillage may bring them back to the surface and trigger rapid germination and growth. Seeds lying on or near the soil surface are more subject to predation, and may dry out and die after beginning to germinate. Seeds on the soil surface, however, are also more likely to germinate successfully and grow than are most buried seeds. Because weed seeds at or near the soil surface are generally more likely to germinate, deteriorate, or become food for seed predators than seeds buried an inch or deeper, delaying tillage after the annual weed seed rain until the following spring generally reduces the number of seeds added to the long-term seed bank (Egley and Williams, 1990).

Based on work in the north-central United States, Davis (2004) recommends a flexible approach to tillage based on existing weed seed species composition. Whereas chisel plowing leaves many seeds fairly near the surface, the moldboard plow sends the majority of seeds to deeper layers. No-till leaves weed seeds at the surface until natural processes incorporate them into the upper layers. As seeds are placed deeper in the soil profile, they become less likely to germinate, but they are also less exposed to attrition through predation and weathering (Table 2). If a weed species with small, relatively short-lived seed, such as giant foxtail and galinsoga, gets out of control and produces a heavy seed rain one season, a moldboard plow can be used to place the seeds deep in the soil profile. It is essential to till shallowly for the following year or two to avoid bringing up the buried seeds before they have lost viability.

Table 2. Effect of weed seed depth placement on dormancy, germination, and mortality[1].

Depth (inches)	Dormancy	Germination	Mortality
0–0.5	Low[2]	High[2]	High
0.5–2	Low	High	Medium
2–5	Medium	Low	Low
5–10	High[3]	Very low[3]	low

[1] From Davis (2004).
[2] Dormancy and germination at 0–0.5 inches depth depends on seed size. Small seeded weeds tend to have low dormancy and high germination at the soil surface, whereas large seeded weeds have medium–high dormancy and low germination at the soil surface.
[3] Note, however, that shorter-lived seed with no or little dormancy mechanism tend to undergo fatal germination at this depth (C. L. Mohler, personal communication, 2008).

Moving Weed Seeds Away From the Crop

Knowing what weed species are most abundantly represented in the seed bank can allow the farmer to estimate when the most weeds are likely to emerge, and adjust the timing of stale or false seedbed practices, crop planting dates, and the choice of crop to reduce weed pressure. Simply delaying final seedbed preparation and crop planting until after most of the season's weed emergence has occurred is often recommended to organic growers as a means to move weeds away from the crop in time. However, delayed planting can reduce yield potential, especially for long-season summer crops like corn and cotton. Diversified vegetable cropping systems, in which different vegetables are planted from March to September, and rotated with winter and summer annual cover crops, offer greater flexibility and more opportunities to “dodge” the major weeds. For example, if common lambsquarters, giant foxtail, and common ragweed have become major problems in summer vegetables, the grower might try planting a vigorous, smothering cover crop in late spring, followed by a fall vegetable. The cover crop will restrict the growth and reproductive capability of the weeds, and fewer additional weeds will emerge in the vegetable.

Usually, weed seed banks are sufficiently diverse that some weeds will emerge in crops planted almost any time. However, the varied planting dates of a diversified vegetable rotation can help prevent any one weed species from building its seed bank up to unmanageably high levels. For example, including both fall planted crops (like garlic, fall greens, and cereal grains) and spring planted crops (like sweet corn, cucumbers, and tomatoes) in a rotation can help reduce both spring and fall germinating weed species.

Ridge tillage is one system that can physically move weed seeds out of crop rows, provided that the seeds are concentrated near or at the soil surface. Just before planting, the tops of the ridges are removed by sweeps that push residues and the top inch or two of soil into the interrow valleys. This moves surface layer weed seeds to the interrow, where they will not compete as intensely with the crop, and they are easier to cultivate out. Later-season cultivations move soil back into the crop row to bury those weeds that emerge within the crop row, and also rebuild the ridges. Late-germinating weeds in the crop row may not significantly affect crop yields, but they can replenish the seed bank. Removing enough soil (about 2 in.) to leave a wide (12-in.), flat bed top for planting is recommended to ensure satisfactory weed control with this strategy (Mohler, 2001b).

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables**. For more on managing the weed seed bank, see:

- **Manage the Weed Seed Bank—Minimize "Deposits" and Maximize "Withdrawals"**
- **Keeping New Weedy Invaders Out of the Field**
- **Promoting Weed Seed Predation and Decay**

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01 **Managing weeds using a stale seedbed approach**

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Several environmental cues, including day/night temperatures, moisture, oxygen levels and light exposure, trigger the germination of weed seeds. Tillage brings weed seeds close to the surface and stimulates their germination. This is especially true for small-seeded weeds, such as common lambsquarters and pigweeds, which require light or temperature fluctuations for germination. Managing weeds using stale seedbeds can reduce weed populations by stimulating the germination of seeds close to the surface so they can be managed prior to planting.

A stale seedbed is created when a field is prepared for planting and then left fallow for several weeks. Weeds are allowed to germinate during the fallow period. Irrigation can even be used to encourage germination in some situations. After a few weeks (usually 2 weeks or more) the emerged weeds are killed before planting. By limiting soil disturbance when the emerged weeds are killed, buried seeds are not exposed to light and other stimuli that encourage germination, and emergence of new weed seedlings is less likely to occur. For example, in machine-harvested cucumbers stale seedbeds prepared 20 to 30 days prior to planting resulted in lower weed numbers and higher cucumber yields compared with shorter stale seedbed windows or not using a stale seedbed.

In conventional systems, weeds that emerge between seedbed preparation and planting can be controlled using herbicides. In organic systems, where tillage and cultivation are relied on heavily for weed control, a propane flamer or mower can be used prior to planting to control weeds in stale seedbeds. A California study on stale seedbed techniques for organic vegetable production on raised beds found that using a propane flamer or clove oil reduced the number of weeds emerging after planting when compared with a rotary cultivator, rotary hoe, top knives or a bed shaper. Furthermore, creating as little disturbance as possible while planting can also decrease weed emergence. In Denmark, punch planting (a technique where a hole is punched into the soil and a seed is dropped in) in combination with using a propane flamer was found to significantly reduce weeds both within and between rows in fodder beets. When considering using a propane flamer it is important to note that it is much more likely to control broadleaf weeds less than two inches in height than larger broadleaf and grass weeds. Further information on flaming can be found in the new MSU Extension bulletin “Integrated Weed Management: Fine Tuning the System, E-3065. (Ordering online at http://www.emdc.msue.msu.edu or call 517-353-6740.)

Is a stale seedbed the same thing as a false seedbed?

No it is not. In a false seedbed you are preparing the soil in advance of planting like a stale seedbed, but the soil is repeatedly cultivated or disturbed to shallow depths between tillage and planting to encourage germination. False seedbeds are designed to deplete the weed seedbank in the top layer of soil.

Other notes regarding stale seedbeds

- Weeds with lengthy emergence periods (for example foxtails) may not be controlled as well as those with shorter emergence periods (common lambsquarters) using a stale seedbed approach.
- After planting, weeds that emerge can continue to be controlled by one or a combination of the low-disturbance methods, including shallow cultivation.
- Remove weeds that escape management before seeds are produced to prevent additions to the weed seedbank.

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MINISTRY OF AGRICULTURE
FOOD & RURAL AFFAIRS

Planning for a Stale Seedbed

Author: Leslie Huffman - Weed Management Specialist (Horticultural Crops)/OMAF
Creation Date: 14 April 2005
Last Reviewed: 14 April 2005

What it is:

The stale seedbed technique is an old method to enhance weed control in seeded crops. It was developed by farmers years ago, even before herbicides were available. This technique works best for later seeded crops, but may be adapted to many systems.

How to begin:

A stale seedbed is created by tilling the soil early, which encourages the weeds to germinate. In most springs, this means tilling the soil by late April, with a good weed flush by mid-May. After the weed cover is established, the emerged weeds are killed without disturbing the soil. This is accomplished by using herbicides like Roundup, Gramoxone or Ignite, or by using non-chemical means like propane flamers, or by mowing very close to the ground. The key is not to disturb the soil, so that fresh weed seeds remain buried. The crop is then seeded or planted with minimal soil disturbance. In many cases, growers find that weeds only sprout in the small area disturbed around the seed or the transplant.

Who should use it:

Many vegetable growers have been using a version of stale seedbeds for some time, especially for seeded crops. Vine crop growers are likely the largest users of the stale seedbed, and onions, carrots, beans, peas, turnips and lettuce can be established quite well in a stale seedbed. As well, transplant growers can also use a stale seedbed with small changes to their transplanters. It was interesting that, in our cover crop demonstrations across Ontario, using newer cover crops like marigolds, pearl millet and sorghum for nematode control, our best stands of cover crops were achieved with a stale seedbed system.

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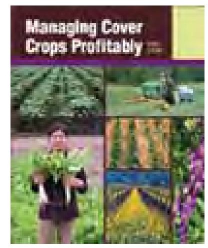

"Managing Cover Crops Profitably" explores how and why cover crops work and provides all the information needed to build cover crops into any farming operation. Revised and updated in 2007, the 3rd edition includes new chapters on brassicas and mustards, six new farm profiles, as well as a comprehensive chapter on the use of cover crops in conservation tillage systems. Updates throughout are based on more than 100 new literature citations and consultations with cover crop researchers and practitioners around the country. Appendices include seed sources and a listing of cover crop experts.

"This is the best book I have ever read. It uses science to explain complex concepts, lays out options for different systems and climates, and allows innovative farmers to digest the information and make their own intelligent decisions. Thank you for the practical advice, acknowledgement of complex tradeoffs, specifics, details and conclusions."
Wolfgang Rougle, Twining Tree Farm, Cottonwood, Cal.

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INTRODUCTION TO CHARTS

The four comprehensive charts that follow can help orient you to the major cover crops most appropriate to your needs and region. Bear in mind that choice of cultivar, weather extremes and other factors may affect a cover crop's performance in a given year.

CHART 1: TOP REGIONAL COVER CROP SPECIES

This chart lists up to five cover crop recommendations per broad bioregion for six different major purposes: N Source, Soil Builder, Erosion Fighter, Subsoil Loosener, Weed Fighter and Pest Fighter. If you know your main goal for a cover crop, Chart 1 can suggest which cover crop entries to examine in the charts that follow and help you determine which major cover narrative(s) to read first.

Disclaimer. The crops recommended here will not be the most successful in all cases within a bioregion, and others may work better in some locations and in some years. The listed cover crops are, however, thought by reviewers to have the best chance of success in most years under current management regimes.

CHART 2: PERFORMANCE AND ROLES

This chart provides relative ratings (with the exception of two columns having quantitative ranges) of what the top covers do best, such as supply or scavenge nitrogen, build soil or fight erosion.

Seasonality has a bearing on some of these ratings. A cover that grows best in spring could suppress weeds better than in fall. Unless otherwise footnoted, however, the chart would rate a cover's performance (relative to the other covers) for the entire time period it is likely to be in the field. Ratings are general for the species, based on measured results and observations over a range of conditions. The individual narratives provide more seasonal details. The added effect of a nurse crop is included in the "Weed Fighter" ratings for legumes usually planted with a grain or grass nurse crop.

Column headings

Legume N Source. Rates legume cover crops for their *relative* ability to supply fixed N. (*Nonlegumes have not been rated* for their biomass nitrogen content, so this column is left blank for nonlegumes.)

Total N. A *quantitative* estimate of the reasonably expected range of total N provided by a legume stand (from all biomass, above- and below ground) in lb. N/A, based mostly on published research. This is total N, not the fertilizer replacement value. *Grasses have not been rated* for their biomass nitrogen content because mature grass residues tend to immobilize N. *Brassicas* are less likely to immobilize N than grasses.

Dry Matter. A *quantitative* estimate of the range of dry matter in lb./A/yr., based largely on published research. As some of this data is based on research plots, irrigated systems or multicut systems, your on-farm result probably would be in the low to midpoint of the dry matter range cited. This estimate is based on fully dry material. "Dry" alfalfa hay is often about 20 percent moisture, so a ton of hay would only be 1,600 lb. of "dry matter."

N Scavenger. Rates a cover crop's ability to take up and store excess nitrogen. Bear in mind that the sooner you plant a cover after main crop harvest—or overseed a cover into the standing crop—the more N it will be able to absorb.

Soil Builder. Rates a cover crop's ability to produce organic matter and improve soil structure. The ratings assume that you plan to use cover crops regularly in your cropping system to provide ongoing additions to soil organic matter.

Erosion Fighter. Rates how extensive and how quickly a root system develops, how well it holds soil against sheet and wind erosion and the influence the growth habit may have on fighting wind erosion.

Weed Fighter. Rates how well the cover crop outcompetes weeds by any means through its life cycle, including killed residue. Note that ratings for the legumes assume they are established with a small-grain nurse crop.

Good Grazing. Rates relative production, nutritional quality and palatability of the cover as a forage.

Quick Growth. Rates the speed of establishment and growth.

Lasting Residue. Rates the effectiveness of the cover crop in providing a long-lasting mulch.

Duration. Rates how well the stand can provide long-season growth.

Harvest Value. Rates the cover crop's economic value as a forage (F) or as a seed or grain crop (S), bearing in mind the relative market value and probable yields.

Cash Crop Interseed. Rates whether the cover crop would hinder or help while serving as a companion crop.

CHART 3A: CULTURAL TRAITS

This chart shows a cover crop's characteristics such as life cycle, drought tolerance, preferred soils and growth habits.The ratings are general for the species, based on measured results and observations over a range of conditions. Choice of cultivar, weather extremes and other factors may affect a cover crop's performance in a given year.

Column headings

Aliases. Provides a few common names for the cover crop.

Type. Describes the general life cycle of the crop.

B = Biennial. Grows vegetatively during its first year and, if it successfully overwinters, sets seed during its second year.

CSA = Cool-Season Annual. Prefers cool temperatures and depending on which Hardiness Zone it is grown in, could serve as a fall, winter or spring cover crop.

SA = Summer Annual. Germinates and matures without a cold snap and usually tolerates warm temperatures.

WA = Winter Annual. Cold-tolerant, usually planted in fall and often requires freezing temperatures or a cold period to set seed.

LP = Long-lived Perennial. Can endure for many growing seasons.

SP = Short-lived Perennial. Usually does not persist more than a few years, if that long.

Hardy Through Zone. Refers to the standard USDA Hardiness Zones. See map on inside front cover. Bear in mind that regional microclimate, weather variations, and other near-term management factors such as planting date and companion species can influence plant performance expectations.

Tolerances. How well a crop is likely to endure despite stress from heat, drought, shade, flooding or low fertility. The best rating would mean that the crop is expected to be fully tolerant.

Habit. How plants develop.
C = Climbing
U = Upright
P = Prostrate
SP = Semi-Prostrate
SU = Semi-Upright

pH Preferred. The pH range in which a species can be expected to perform reasonably well.

Best Established. The season in which a cover crop is best suited for planting and early growth. Note that this can vary by region and that it's important to ascertain local planting date recommendations for specific cover crops.
Season: F = Fall ; Sp = Spring; Su = Summer; W = Winter
Time: E = Early; L = Late; M = Mid

Minimum Germination Temperature. The minimum soil temperature (F) generally required for successful germination and establishment.

CHART 3B: PLANTING

Depth. The recommended range of seeding depth (in inches), to avoid either overexposure or burying too deeply.

Rate. Recommended seeding rate for drilling and broadcasting a pure stand in lb./A, bu/A. and oz./100 sq. ft., assuming legal standards for germination percentage. Seeding rate will depend on the cover crop's primary purpose and other factors. See the narratives for more detail about establishing a given cover crop. Pre-inoculated ("rhizo-coated") legume seed weighs about one-third more than raw seed. Increase seeding rate by one-third to plant the same amount of seed per area.

Cost. Material costs (seed cost only) in dollars per pound, based usually on a 50-lb. bag as of fall 2006. Individual species vary markedly with supply and demand. Always confirm seed price and availability before ordering, and before planning to use less common seed types.

Cost/A. Seed cost per acre based on the midpoint between the high and low of reported seed prices as of fall 1997 and the midpoint recommended seeding rate for drilling and broadcasting. Your cost will depend on actual seed cost and seeding rate. Estimate excludes associated costs such as labor, fuel and equipment.

Inoculant Type. The recommended inoculant for each legume. Your seed supplier may only carry one or two common inoculants. You may need to order inoculant in advance. See *Seed Suppliers*, p. 195.

Reseeds. Rates the likelihood of a cover crop re-establishing through self-reseeding if it's allowed to mature and set seed. Aggressive tillage will bury seed and reduce germination. Ratings assume the tillage system has minimal effect on reseeding. Dependable reseeding ability is valued in some orchard, dryland grain and cotton systems, but can cause weed problems in other systems. See the narratives for more detail.

CHARTS 4A AND 4B

These charts provide relative ratings of other management considerations—benefits and possible drawbacks—that could affect your selection of cover crop species.

The till-kill rating assumes tillage at an appropriate stage. The mow-kill ratings assume mowing at flowering, but before seedheads start maturing. See sectional narratives for details.

Ratings are based largely on a combination of published research and observations of farmers who have grown specific covers. Your experience with a given cover could be influenced by site-specific factors, such as your soil condition, crop rotation, proximity to other farms, weather extremes, etc.

CHART 4A: POTENTIAL ADVANTAGES

Soil Impact. Assesses a cover's relative ability to loosen subsoil, make soil P and K more readily available to crops, or improve topsoil.

Soil Ecology. Rates a cover's ability to fight pests by suppressing or limiting damage from nematodes, soil disease from fungal or bacterial infection, or weeds by natural herbicidal (allelopathic) or competition/smothering action. Researchers report difficulty in conclusively documenting allelopathic activity distinct from other cover crop effects, and nematicidal impacts are variable, studies show. These are general, tentative ratings in these emerging aspects of cover crop influence.

Other. Indicates likelihood of attracting beneficial insects, of accommodating field traffic (foot or vehicle) and of fitting growing windows or short duration.

CHART 4B: POTENTIAL DISADVANTAGES

Increase Pest Risks. Relative likelihood of a cover crop becoming a weed, or contributing to a likely pest risk. Overall, growing a cover crop rarely causes pest problems, but certain cover crops may contribute to particular pest, disease or nematode problems in localized areas, for example by serving as an alternate host to the pest. See the narratives for more detail.

▼ Readers note the shift in meaning for symbols on this chart only.

Management Challenges. Relative ease or difficulty of establishing, killing or incorporating a stand. "Till-kill" refers to killing by plowing, disking or other tillage. "Mature incorporation" rates the difficulty of incorporating a relatively mature stand. Incorporation will be easier when a stand is killed before maturity or after some time elapses between killing and incorporating.

Chart 1 **TOP REGIONAL COVER CROP SPECIES**[1]

Bioregion	N Source	Soil Builder	Erosion Fighter	Subsoil Loosener	Weed Fighter	Pest Fighter
Northeast	red cl, hairy v, berseem, swt cl	ryegrs, swt cl, sorghyb, rye	rye, ryegrs, sub cl, oats	sorghyb, swt cl, forad	sorghyb, ryegrs, rye, buckwheat	rye, sorghyb, rape
Mid-Atlantic	hairy v, red cl, berseem, crim cl	ryegrs, rye, swt cl, sorghyb	sub cl, cowpeas, rye, ryegrs	sorghyb, swt cl, forad	rye, ryegrs, oats, buckwheat	rye, sorghyb, rape
Mid-South	hairy v, sub cl, berseem, crim cl	ryegrs, rye, sub cl, sorghyb	sub cl, cowpeas, rye, ryegrs	sorghyb, swt cl	buckwheat, ryegrs, sub cl, rye	rye, sorghyb
Southeast Uplands	hairy v, red cl, berseem, crim cl	ryegrs, rye, sorghyb, swt cl	sub cl, cowpeas, rye, ryegrs	sorghyb, swt cl	buckwheat, ryegrs, sub cl, rye	rye, sorghyb
Southeast Lowlands	winter peas, sub cl, hairy v, berseem, crim cl	ryegrs, rye, sorghyb, sub cl	sub cl, cowpeas, rye, ryegrs, sorghyb	sorghyb	berseem, rye, wheat, cowpeas, oats, ryegrs	rye, sorghyb
Great Lakes	hairy v, red cl, berseem, crim cl	ryegrs, rye, sorghyb, ryegrs, swt cl	oats, rye, ryegrs	sorghyb, swt cl, forad	berseem, ryegrs, rye, buckwht, oats	rye, sorghyb, rape
Midwest Corn Belt	hairy v, red cl, berseem, crim cl	rye, barley, sorghyb, swt cl	wht cl, rye, ryegrs, barley	sorghyb, swt cl, forad	rye, ryegrs, wheat, buckwht, oats	rye, sorghyb
Northern Plains	hairy v, swt cl, medics	rye, barley, medic, swt cl	rye, barley	sorghyb, swt cl	medic, rye, barley	rye, sorghyb
Southern Plains	winter peas, medic, hairy v	rye, barley, medic	rye, barley	sorghyb, swt cl	rye, barley	rye, sorghyb
Inland Northwest	winter peas, hairy v	medic, swt cl, rye, barley	rye, barley	sorghyb, swt cl	rye, wheat, barley	rye, mustards, sorghyb
Northwest Maritime	berseem, sub cl, lana v, crim cl	ryegrs, rye, sorghyb, lana v	wht cl, rye, ryegrs, barley	sorghyb, swt cl	ryegrs, lana v, oats, wht cl	rye, mustards
Coastal California	berseem, sub cl, lana v, medic	ryegrs, rye, sorghyb, lana v	wht cl, cowpeas, rye, ryegrs	sorghyb, swt cl	rye, ryegrs, berseem, wht cl	sorghyb, crim cl, rye
Calif. Central Valley	winter peas, lana v, sub cl, medic	medic, sub cl	wht cl, barley, rye, ryegrs	sorghyb, swt cl	ryegrs, wht cl, rye, lana v	sorghyb, crim cl, rye
Southwest	medic, sub cl	sub cl, medic, barley	barley, sorghyb		medic, barley	

[1]ryegrs=annual ryegrass. buckwht=buckwheat. forad=forage radish. rape=rapeseed. sorghyb=sorghum-sudangrass hybrid. berseem=berseem clover. winter peas=Austrian winter pea. crim cl=crimson clover. hairy v=hairy vetch. red cl=red clover. sub cl=subterranean clover. swt cl=sweetclover. wht cl=white clover. lana v=LANA woollypod vetch.

Chart 2 **PERFORMANCE AND ROLES**

	Species	Legume N Source	Total N (lb./A)[1]	Dry Matter (lb./A/yr.)	N Scavenger[2]	Soil Builder[3]	Erosion Fighter[4]	Weed Fighter	Good Grazing[5]	Quick Growth
NONLEGUMES	Annual ryegrass *p. 74*			2,000–9,000	◕	◕	◕	◕	◕	◕
	Barley *p. 77*			2,000–10,000	◕	◕	●	◕	◕	◕
	Oats *p. 93*			2,000–10,000	◕	◑	◕	●	◑	●
	Rye *p. 98*			3,000–10,000	●	●	●	●	◑	●
	Wheat *p. 111*			3,000–8,000	◕	◕	◕	◕	◕	◕
	Buckwheat *p. 90*			2,000–4,000	○	◑	◔	●	○	●
	Sorghum-sudan. *p. 106*			8,000–10,000	●	●	●	◕	◕	●
BRASSICAS	Mustards *p.81*		30–120	3,000–9,000	◑	◕	◕	◕	◑	◕
	Radish *p. 81*		50–200	4,000–7,000	●	◕	◕	●	◑	◕
	Rapeseed *p. 81*		40–160	2,000–5,000	◕	◑	◕	◕	◑	◕
LEGUMES	Berseem clover *p. 118*	●	75–220	6,000–10,000	◕	◕	◕	●	●	●
	Cowpeas *p. 125*	●	100–150	2,500–4,500	◔	◑	●	●	◑	◕
	Crimson clover *p. 130*	◕	70–130	3,500–5,500	◑	◕	◕	◕	●	◑
	Field peas *p. 135*	●	90–150	4,000–5,000	◔	◑	◕	◑	◕	◕
	Hairy vetch *p. 142*	●	90–200	2,300–5,000	◔	◕	◑	◑	◑	◔
	Medics *p. 152*	◑	50–120	1,500–4,000	◔	◑	◑	◕	◕	●
	Red clover *p. 159*	◕	70–150	2,000–5,000	◑	◕	◑	◕	●	◔
	Subterranean clovers *p.164*	●	75–200	3,000–8,500	◔	◕	◕	●	◕	◑
	Sweetclovers *p. 171*	●	90–170	3,000–5,000	◔	●	◕	◕	◕	◑
	White clover *p. 179*	●	80–200	2,000–6,000	◔	◑	◕	◕	●	◔
	Woollypod vetch *p. 185*	●	100–250	4,000–8,000	◑	●	◑	●	◑	◕

[1]**Total N**—Total N from all plant. Grasses not considered N source. [2]**N Scavenger**—Ability to take up/store excess nitrogen.
[3]**Soil Builder**—Organic matter yield and soil structure improvement. [4]**Erosion Fighter**—Soil-holding ability of roots and total plant.
[5]**Good Grazing**—Production, nutritional quality and palatability. Feeding pure legumes can cause bloat.

○=Poor; ◔=Fair; ◑=Good; ◕=Very Good; ●=Excellent

Chart 2 **PERFORMANCE AND ROLES** continued

	Species	Lasting Residue[1]	Duration[2]	Harvest Value[3] F*	Harvest Value[3] S*	Cash Crop Interseed[4]	Comments
NONLEGUMES	Annual ryegrass	Very Good	Very Good	Good	Fair	Excellent	Heavy N and H2O user; cutting boosts dry matter significantly.
NONLEGUMES	Barley	Excellent	Good	Very Good	Good	Very Good	Tolerates moderately alkaline conditions but does poorly in acid soil < pH 6.0.
NONLEGUMES	Oats	Good	Fair	Good	Good	Excellent	Prone to lodging in N-rich soil.
NONLEGUMES	Rye	Excellent	Very Good	Fair	Fair	Very Good	Tolerates triazine herbicides.
NONLEGUMES	Wheat	Very Good	Very Good	Good	Very Good	Fair	Heavy N and H2O user in spring.
NONLEGUMES	Buckwheat	Poor	Fair	Poor	Fair	Very Good	Summer smother crop; breaks down quickly.
NONLEGUMES	Sorghum-sudangrass	Very Good	Excellent	Excellent	Poor	Poor	Mid-season cutting increases yield & root penetration.
BRASSICAS	Mustards	Fair	Good	Poor	Fair	Poor	Suppresses nematodes and weeds.
BRASSICAS	Radish	Fair	Good	Very Good	Fair	Fair	Good N scavenging and weed control; N released rapidly.
BRASSICAS	Rapeseed	Good	Very Good	Fair	Excellent	Poor	Suppresses *Rhizoctonia.*
LEGUMES	Berseem clover	Good	Excellent	Excellent	Very Good	Good	Very flexible cover crop, green manure, forage.
LEGUMES	Cowpeas	Fair	Excellent	Good	Good	Good	Season length, habit vary by cultivar.
LEGUMES	Crimson clover	Good	Fair	Excellent	Very Good	Excellent	Established easily, grows quickly if planted early in fall; matures early in spring.
LEGUMES	Field peas	Fair	Good	Excellent	Very Good	Excellent	Biomass breaks down quickly.
LEGUMES	Hairy vetch	Fair	Very Good	Fair	Very Good	Good	Bi-culture with small grain expands seasonal adaptability.
LEGUMES	Medics	Good	Very Good	Good	Good	Good	Use annual medics for interseeding.
LEGUMES	Red clover	Fair	Good	Excellent	Very Good	Excellent	Excellent forage, easily established; widely adapted.
LEGUMES	Subterranean clover	Very Good	Very Good	Very Good	Poor	Excellent	Strong seedlings, quick to nodulate.
LEGUMES	Sweetclovers	Very Good	Very Good	Very Good	Good	Good	Tall stalks, deep roots in second year.
LEGUMES	White clover	Fair	Excellent	Very Good	Good	Very Good	Persistent after first year.
LEGUMES	Woollypod vetch	Fair	Very Good	Fair	Very Good	Good	Reseeds poorly if mowed within 2 months of seeddrop; overgrazing can be toxic.

[1]**Lasting Residue**—Rates how long the killed residue remains on the surface. [2]**Duration**—Length of vegetative stage. [3]**Harvest Value**—Economic value as a forage (F) or as seed (S) or grain. [4]**Cash Crop Interseed**—Rates how well the cover crop will perform with an appropriate companion crop.

○=Poor; ◔=Fair; ◑=Good; ◕=Very Good; ●=Excellent

Chart 3A **CULTURAL TRAITS**

	Species	Aliases	Type[1]	Hardy through Zone[2]	Tolerances: heat	drought	shade	flood	low fert	Habit[3]	pH (Pref.)	Best Established[4]	Min. Germin. Temp.
NONLEGUMES	Annual ryegrass *p. 74*	Italian ryegrass	WA	6	Fair	Fair	Very Good	Very Good	Fair	U	6.0–7.0	ESp, LSu, EF, F	40F
	Barley *p. 77*		WA	7	Very Good	Very Good	Good	Fair	Very Good	U	6.0–8.5	F, W, Sp	38F
	Oats *p. 93*	spring oats	CSA	8	Fair	Fair	Fair	Good	Good	U	4.5–7.5	LSu, ESp W in 8+	38F
	Rye *p. 98*	winter, cereal, or grain rye	CSA	3	Good	Very Good	Very Good	Good	Excellent	U	5.0–7.0	LSu, F	34F
	Wheat *p. 111*		WA	4	Good	Good	Good	Poor	Good	U	6.0–7.5	LSu, F	38F
	Buckwheat *p. 90*		SA	NFT	Good	Poor	Fair	Fair	Fair	U/SU SU	5.0–7.0	Sp to LSu	50F
	Sorghum–sudan. *p. 106*	Sudax	SA	NFT	Excellent	Excellent	Good	Good	Good	U	6.0–7.0	LSp, ES	65F
BRASSICAS	Mustards *p.81*	brown, oriental white, yellow	WA, CSA	7	Good	Very Good	Good	Fair	Fair	U	5.5–7.5	Sp, LSu	40F
	Radish *p. 81*	oilseed, Daikon, forage radish	CSA	6	Good	Fair	Good	Fair	Fair	U	6.0–7.5	Sp, LSu, EF	45F
	Rapeseed *p. 81*	rape, canola	WA	7	Fair	Good	Good	Fair	Fair	U	5.5–8	F, Sp	41F
LEGUMES	Berseem clover *p. 118*	BIGBEE, multicut	SA, WA	7	Very Good	Good	Very Good	Good	Good	U/SU SU	6.2–7.0	ESp, EF	42F
	Cowpeas *p. 125*	crowder peas, southern peas	SA	NFT	Excellent	Very Good	Good	Fair	Excellent	SU/C	5.5–6.5	ESu	58F
	Crimson clover *p. 130*		WA, SA	7	Good	Fair	Very Good	Fair	Good	U/SU	5.5–7.0	LSu/ESu	
	Field peas *p. 135*	winter peas, black peas	WA	7	Fair	Good	Fair	Fair	Fair	C	6.0–7.0	F, ESp	41F
	Hairy vetch *p. 142*	winter vetch	WA,CSA	4	Fair	Good	Good	Fair	Fair	C	5.5–7.5	EF, ESp	60F
	Medics *p. 152*		SP, SA	4/7	Excellent	Very Good	Very Good	Fair	Good	P/Su	6.0–7.0	EF, ESp, ES	45F
	Red clover *p. 159*		SP, B	4	Fair	Fair	Very Good	Good	Fair	U	6.2–7.0	LSu; ESp	41F
	Subterranean cl. *p. 164*	subclover	CSA	7	Good	Very Good	Very Good	Good	Excellent	P/SP	5.5–7.0	LSu, EF	38F
	Sweetclovers *p. 171*		B, SA	4	Very Good	Excellent	Fair	Fair	Excellent	U	6.5–7.5	Sp/S	42F
	White clover *p. 179*	white dutch ladino	LP, WA	4	Good	Good	Very Good	Very Good	Good	P/SU	6.0–7.0	LW, E to LSp, EF	40F
	Woollypod vetch *p. 185*	Lana	CSA	7	Very Good	Very Good	Good	Good	Very Good	SP/C	6.0–8.0	F	

[1]B=Biennial; CSA=Cool season annual; LP=Long-lived perennial; SA=Summer annual; SP=Short-lived perennial; WA=Winter annual
[2]See USDA Hardiness Zone Map, inside front cover. NFT=Not frost tolerant. [3]C=Climbing; U=Upright; P=Prostrate; SP=Semi-prostrate; SU=Semi-upright. [4]E=Early; M=Mid; L=Late; F=Fall; Sp=Spring; Su=Summer; W=Winter

○=Poor; ◔=Fair; ◑=Good; ◕=Very Good; ●=Excellent

Chart 3B **PLANTING**

	Species	Depth	Seeding Rate: Drilled		Seeding Rate: Broadcast			Cost ($/lb.)[1]	Cost/A (median)[2]		Inoc. Type	Reseeds[3]
			lb./A	bu/A	lb./A	bu/A	oz./100 ft^2		drilled	broadcast		
NONLEGUMES	Annual ryegrass	0–1/2	10–20	.4–.8	20–30	.8–1.25	1	.70–1.30	12	24		U
NONLEGUMES	Barley	3/4–2	50–100	1–2	80–125	1.6–2.5	3-5	.17–.37	20	27		S
NONLEGUMES	Oats	1/2–1 1/2	80–110	2.5–3.5	110–140	3.5–4.5	4–6	.13–.37	25	33		S
NONLEGUMES	Rye	3/4–2	60–120	1-2	90–160	1.5–3.0	4–6	.18–.50	25	35		S
NONLEGUMES	Wheat	1/2–1 1/2	60–120	1–2	60–150	1–2.5	3–6	.10–.30	18	22		S
NONLEGUMES	Buckwheat	1/2–1 1/2	48–70	1–1.4	50–90	1.2–1.5	3–4	.30–.75	32	38		R
NONLEGUMES	Sorghum-sudangrass	1/2–1 1/2	35	1	40–50	1–1.25	2	.40–1.00	26	34		S
BRASSICAS	Mustards	1/4–3/4	5–12		10–15		1	1.50–3.00	16	24		U
BRASSICAS	Radish	1/4–1/2	8–13		10–20		1	1.50–2.50	22	32		S
BRASSICAS	Rapeseed	1/4–3/4	5–10		8–14		1	1.00–2.00	11	16		S
LEGUMES	Berseem clover	1/4–1/2	8–12		15–20		2	1.70–2.50	22	39	crimson, berseem	N
LEGUMES	Cowpeas	1–1 1/2	30–90		70–120		5	.85–1.50	71	113	cowpeas, lespedeza	S
LEGUMES	Crimson clover	1/4–1/2	15-20		22–30		2–3	1.25–2.00	27	40	crimson, berseem	U
LEGUMES	Field peas	1 1/2–3	50–80		90–100		4	.61–1.20	50	75	pea, vetch	S
LEGUMES	Hairy vetch	1/2-1 1/2	15–20		25–40		2	1.70–2.50	35	65	pea, vetch	S
LEGUMES	Medics	1/4–1/2	8–22		12–26		2/3	2.50–4.00	58	75	annual medics	R
LEGUMES	Red clover	1/4–1/2	8–10		10–12		3	1.40–3.30	23	28	red cl, wht cl	S
LEGUMES	Subterranean clover	1/4–1/2	10–20		20–30		3	2.50–3.50	45	75	clovers, sub, rose	U
LEGUMES	Sweetclovers	1/4–1.0	6–10		10–20		1.5	1.00–3.00	16	32	alfalfa, swt cl	U
LEGUMES	White clover	1/4–1/2	3–9		5–14		1.5	1.10–4.00	19	30	red cl, wht cl	R
LEGUMES	Woollypod vetch	1/2–1	10–30		30–60		2-3	1.25–1.60	30	65	pea, vetch	S

[1]Per pound in 50-lb. bags as of summer/fall 2006; To locate places to buy seed, see *Seed Suppliers* (p. 166).
[2]Mid-point price at mid-point rate, seed cost only. [3]**R**=Reliably; **U**=Usually; **S**=Sometimes; **N**=Never (reseeds).

Chart 4A **POTENTIAL ADVANTAGES**

Group	Species	Soil Impact			Soil Ecology				Other		
		subsoiler	free P&K	loosen topsoil	nematodes	disease	allelopathic	choke weeds	attract beneficials	bears traffic	short windows
NONLEGUMES	Annual ryegrass *p. 74*	Good	Good	Excellent	Good	Good	Good	Excellent	Fair	Excellent	Excellent
NONLEGUMES	Barley *p. 77*	Good	Good	Very Good	Fair	Good	Very Good	Very Good	Good	Good	Excellent
NONLEGUMES	Oats *p. 93*	Poor	Fair	Very Good	Poor	Good	Very Good	Excellent	Poor	Good	Excellent
NONLEGUMES	Rye *p. 98*	Fair	Very Good	Excellent	Good	Very Good	Excellent	Excellent	Fair	Very Good	Excellent
NONLEGUMES	Wheat *p. 111*	Good	Very Good	Very Good	Fair	Fair	Fair	Very Good	Fair	Good	Good
NONLEGUMES	Buckwheat *p. 90*	Poor	Excellent	Very Good	Fair	Poor	Very Good	Excellent	Excellent	Poor	Excellent
NONLEGUMES	Sorghum-sudangrass *p. 106*	Excellent	Good	Good	Very Good	Very Good	Excellent	Excellent	Good	Good	Excellent
BRASSICAS	Mustards *p.81*	Fair	Good	Very Good	Very Good	Very Good	Very Good	Very Good	Good	Good	Very Good
BRASSICAS	Radish *p. 81*	Excellent	Very Good	Good	Very Good	Good	Very Good	Excellent	Fair	Fair	Very Good
BRASSICAS	Rapeseed *p. 81*	Good	Fair	Good	Very Good	Good	Very Good	Good	Good	Fair	Good
LEGUMES	Berseem clover *p. 118*	Fair	Very Good	Very Good	Poor	Poor	Fair	Very Good	Good	Fair	Very Good
LEGUMES	Cowpeas *p. 125*	Good	Good	Very Good	Poor	Poor	Poor	Excellent	Very Good	Poor	Excellent
LEGUMES	Crimson clover *p. 130*	Fair	Good	Good	Fair	Good	Fair	Good	Very Good	Fair	Good
LEGUMES	Field peas *p. 135*	Fair	Fair	Very Good	Good	Very Good	Fair	Very Good	Very Good	Fair	Very Good
LEGUMES	Hairy vetch *p. 142*	Good	Good	Very Good	Fair	Good	Good	Very Good	Excellent	Poor	Poor
LEGUMES	Medics *p. 152*	Good	Fair	Fair	Good	Good	Fair	Very Good	Fair	Fair	Excellent
LEGUMES	Red clover *p. 159*	Very Good	Very Good	Good	Fair	Fair	Good	Good	Very Good	Good	Good
LEGUMES	Subterranean clover *p. 164*	Poor	Fair	Good	Fair	Fair	Very Good	Excellent	Very Good	Very Good	Very Good
LEGUMES	Sweetclovers *p. 171*	Excellent	Excellent	Excellent	Fair	Fair	Fair	Good	Very Good	Good	Poor
LEGUMES	White clover *p. 179*	Fair	Fair	Very Good	Poor	Poor	Good	Very Good	Good	Excellent	Good
LEGUMES	Woollypod vetch *p. 185*	Very Good	Good	Very Good	Fair	Fair	Good	Excellent	Very Good	Fair	Good

○=Poor; ◔=Fair; ◑=Good; ◕=Very Good; ●=Excellent

Chart 4B **POTENTIAL DISADVANTAGES**

Note change in symbols ○ = problem ● = not a problem

Group	Species	Increase Pest Risks: weed potential	Increase Pest Risks: insects/ nematodes	Increase Pest Risks: crop disease	Management Challenges: hinder crops	Management Challenges: establish	Management Challenges: till-kill	Management Challenges: mow-kill	Management Challenges: mature incorp.	Comments Pro/Con
NONLEGUMES	Annual ryegrass	○[1]	◕	◕	◑	●	●	●	◑	If mowing, leave 3-4" to ensure regrowth.
NONLEGUMES	Barley	◔	◔	◔	◑	●	●	●	○	Can be harder than rye to incorporate when mature.
NONLEGUMES	Oats	●	◑	◕	◑	●	●	◔	◑	Cleaned, bin-run seed will suffice.
NONLEGUMES	Rye	◔	◑	◕	◔	◕	◕	●	○	Can become a weed if tilled at wrong stage.
NONLEGUMES	Wheat	◑	◔	◔	◑	●	●	◕	◑	Absorbs N and H_2O heavily during stem growth, so kill before then.
NONLEGUMES	Buckwheat	○	◕	●	●	●	●	●	●	Buckwheat sets seed quickly.
NONLEGUMES	Sorghum–sudangrass	◑	◕	●	◔	●	◕	◕	◔	Mature, frost-killed plants become quite woody.
BRASSICAS	Mustards	◔	◕	●	◑	●	●	◔	●	Great biofumigation potential; winterkills at 25° F.
BRASSICAS	Radish	◑	◕	●	●	●	●	●	●	Winter kills at 25° F; cultivars vary widely.
BRASSICAS	Rapeseed	◔	◔	●	◑	●	◑	◔	◕	Canola has less biotoxic activity than rape.
LEGUMES	Berseem clover	●	◑	◕	●	●	◔	◔	◕	Multiple cuttings needed to achieve maximum N.
LEGUMES	Cowpeas	●	◑	◕	●	●	●	●	●	Some cultivars, nematode resistant.
LEGUMES	Crimson clover	◑	○	◕	●	◕	◕	◕	◕	Good for underseeding, easy to kill by tillage or mowing.
LEGUMES	Field peas	●	◑	◔	●	●	●	●	◕	Susceptible to *sclerotinia* in East.
LEGUMES	Hairy vetch	◑	◑	●	●	◑	◔	●	◑	Tolerates low fertility, wide pH range, cold or fluctuating winters.
LEGUMES	Medics	◑	◔	●	◕	◕	◔	◕	◕	Perennials easily become weedy.
LEGUMES	Red clover	◑	◔	◕	●	◕	◑	◔	◕	Grows best where corn grows well.
LEGUMES	Subterranean clover	◑	○	◑	◑	●	◔	○	◕	Cultivars vary greatly.
LEGUMES	Sweetclovers	◔	◔	●	◑	●	◑	◕	◔	Hard seed possible problem; does not tolerate seeding year mowing
LEGUMES	White clover	◑	◑	◕	◔	◕	○	◑	◕	Can be invasive; survives tillage.
LEGUMES	Woollypod vetch	◑	◑	◔	◑	◑	◕	●	◔	Hard seed can be problematic; resident vegetation eventually displaces.

[1]Note change in symbols, this page only: ○ = problem. ◔ = Could be a moderate problem. ◑ = Could be a minor problem. ◕ = Occasionally a minor problem. ● = not a problem

COVER CROP MIXTURES EXPAND POSSIBILITIES

Mixtures of two or more cover crops are often more effective than planting a single species. Cover crop mixtures offer the best of both worlds, combining the benefits of grasses and legumes, or using the different growth characteristics of several species to fit your needs.

You can use cover crop mixtures to improve:

- Winter survival
- Ground cover
- Use of solar energy
- Biomass and N production
- Weed control
- Duration of active growing period
- Range of beneficial insects attracted
- Tolerance of adverse conditions
- Forage options
- Response to variable soil traits

Disadvantages of cover crop mixtures may include:

- Higher seed cost
- Too much residue
- More complicated management
- Difficult to seed

Crop mixtures can reduce risk in cropping systems because each crop in the mix may respond differently to soil, pest and weather conditions. In forage or grazing systems, for example, a mix of rye, wheat and barley is more nutritious, can be grazed over a longer period of time and is less likely to be devastated by a single disease.

Using drought-tolerant plants in a perennial mix builds in persistence for dry years. Using a number of cover crops with "hard seed" that takes many months to germinate also improves coverage over a broader range of conditions.

Mixing cultivars of a single species with varied maturity dates and growth habits maintains optimum benefits for a longer time. Orchardists in California mix subclovers to keep weeds at bay all season. One cultivar comes on early, then dies back as two later cultivars—one tall and one short—come on strong. Because they reseed themselves, the cooperative trio persists year after year.

Sometimes you don't know how much N may be left after cash crop harvest. Do you need a grass to scavenge leftover N, or a legume to provide fixed N? A grass/legume cover crop mixture adjusts to the amount of available soil N: If there is a lot of N, the grass dominates; if there is not much available soil N, the legume will tend to dominate a mixture. In either case, you get the combined benefit of N scavenging by the grass cover crop and N additions from the legume cover crop.

Mixing low-growing and taller crops, or fast-starting grasses and slow-developing legumes, usually provides better erosion control because more of the ground is covered. The vegetation intercepts more raindrops before they can dislodge soil particles. Sunlight is used more efficiently because light that passes through the tall crop is captured by the low-growing crop.

Adding grasses to a fall-seeded legume improves soil coverage over winter and increases the root mass to stabilize topsoil. A viny crop like vetch will climb a grass, so it can get more light and fix more N, or so it can be harvested more easily for seed. A faster-growing crop serves as a nurse crop for a slow-growing crop, while covering the ground quickly for erosion control. The possibilities are endless!

Mixtures can complicate management, however. For example:

- They may cost more to seed. Seeding rates for each component of the mix are usually lower than for sole-crop plantings, but the total seed cost may still be more.
- The best time to kill one crop may not be the best for another crop, so a compromise date may be used.
- If you use herbicides, your choices may be limited when you plant a mixture of legumes and nonlegumes.
- Sometimes you can end up with more residue than your equipment can handle.

Welcome! What's your local institution?

- University of Maryland
- University of Maryland, Eastern Shore
- Select a different institution

How Cover Crops Suppress Weeds

Last Updated: March 23, 2010

eOrganic author: Mark Schonbeck, Virginia Association for Biological Farming

Introduction

A growing cover crop can suppress weeds in several ways:

- Direct competition
- Allelopathy—the release of plant growth–inhibiting substances
- Blocking stimuli for weed seed germination
- Altering soil microbial communities to put certain weeds at a disadvantage

After a cover crop is tilled in, mowed, rolled, or otherwise terminated, its residues can prolong weed suppression by:

- Physically hindering seedling emergence (if residues are left on the surface as mulch)
- Releasing allelopathic substances during decomposition
- Promoting fungi that are pathogenic to weed seedlings
- Tying up nitrogen (N) (when low-N residues are incorporated into soil)

Competition

A vigorous, fast-growing cover crop competes strongly with weeds for space, light, nutrients, and moisture, and can thereby reduce weed growth by 80–100% for the duration of the cover crop's life cycle. Timely cover crop plantings occupy the empty niches that occur in vegetable production systems:

- After vegetable harvest
- Over winter
- Before planting a late-spring or summer vegetable
- Between wide-spaced rows of an established crop

Buckwheat (Fig. 1, left), soybean, and cowpea planted in warm soil can cover the ground within two or three weeks. This "canopy closure" puts tiny, emerging weeds in the shade and hinders their growth. Summer or winter annual grasses like sorghum–sudangrass, various millets (Fig. 1, right), oats, rye, and wheat form dense, fibrous root systems that appropriate soil moisture and nutrients, leaving less for the weeds.

Combining a grass with a legume or other broadleaf crop is often more effective than growing either alone (Fig. 2).

Figure 1. This buckwheat (left), planted immediately after a vegetable harvest, has nearly covered the ground within 15 days after planting (DAP). Pearl millet (right) has formed substantial biomass by 42 DAP and effectively crowded out most weeds. Figure credits: Mark Schonbeck, Virginia Association for Biological Farming.

Figure 2. A cover crop biculture of grass–legume can compete more effectively against weeds than either component alone. In this mature winter cover crop, the cereal rye has permeated the topsoil with a dense fibrous root system and provided support for the hairy vetch, allowing the latter to grow more vigorously and cast dense shade on the soil surface. Very little weed biomass was found in this cover crop, photographed here in late May on Cape Cod, MA. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Fast-growing millets, forage soybeans, and sorghum–sudangrass can attain heights of four to seven feet, and aboveground dry biomass of four tons per acre within 65–70 days after planting (DAP). The grasses can mop up 100–150 lb N per acre in that time, and soybeans can fix up to 200 lb N per acre. Winter cereal grains, especially rye, can grow at temperatures just a few degrees above freezing, and thereby get a jump on early spring weeds. Oats and field peas planted in early spring can reach three to four feet and three tons per acre by the summer solstice.

> Watch this video clip for an excellent example of the use of sorghum–sudangrass ("sudex") to produce a high biomass, weed-suppressive cover crop (Grubinger, 2004).

Clovers get off to a slow start and are not initially good competitors. However, clover seedlings, especially red clover, are quite shade-tolerant; thus clovers can be interplanted or overseeded into standing vegetable crops. When the vegetable is harvested and cleared off, the established clover seedlings grow rapidly, and taller varieties—such as mammoth red, crimson, berseem, and ladino clovers—can compete well against postharvest weeds.

Competition from a strong cover crop can virtually shut down the growth of many annual weeds emerging from seed. Perennial weeds that emerge or regenerate from roots, rhizomes, or tubers are more difficult to suppress, but even their growth and reproduction can be substantially reduced by the most aggressive cover crops.

As long as the cover crop is actively growing, intercepting light, and utilizing soil moisture and nutrients, later-emerging weeds have little opportunity to grow. Tilling the cover crop into the soil as a green manure terminates the competitive effect, leaving an open niche which should be occupied by planting a subsequent crop as soon as practical.

Allelopathy

All plants give off various substances that can affect the growth of other plants. Active compounds may be exuded by living plant roots, washed off the leaves and shoots into the soil by rainfall, or released from decaying residues. These **allelochemicals**, some of which are potent enough to be considered nature's herbicides, have the greatest impact on germinating seeds, seedlings, and young plants, retarding their growth, causing visible damage to roots or shoots, or even killing them outright. Allelopathic effects strong enough to contribute significantly to weed control in field conditions have been documented for rye and other winter cereal grains, sorghum and sorghum–sudangrass hybrids, lablab bean, rapeseed, buckwheat, and subterranean clover (Putnam and Tang, 1986; Rice, 1995; Boydston and Hang, 1995), as well as forage and daikon radishes (Fig. 3).

Cover crops in the brassica family, including rapeseed, mustards, and radishes, contain a number of compounds called glucosinolates, which break down into powerful volatile allelochemicals called isothiocyanates during residue decomposition. In field trials, brassica cover crops have suppressed weed growth for several weeks or months after the cover crop was tilled in (Al-Katib et al., 1997; Boydston and Hang, 1995) or winter-killed (Fig. 3).

Figure 3. A daikon radish cover crop, sown in August, covered the ground with a heavy canopy by midautumn (left). The crop winter-killed and its residues mostly disappeared by March, yet Professor Ron

Morse of Virginia Tech could find almost no winter weeds in the radish plots (center), whereas common chickweed grew vigorously through the more persistent residues of other winter-killed cover crops (right). This suggests that the radish exerted a lasting suppressive effect against chickweed, yet vegetable crops sown or transplanted in April suffered no ill effects. Figure credits: Mark Schonbeck, Virginia Association for Biological Farming.

Because each plant species gives off a unique combination of potentially allelopathic substances, and is itself sensitive to some allelochemicals and tolerant to others, allelopathic interactions are often species specific. For example, winter rye and its residues are quite active against pigweeds, lambsquarters, purslane, and crabgrass, and far less so against ragweeds, sicklepod, and morning glories. Sunflower and subclover suppress morning glories, ande sorghum can inhibit purple nutsedge and Bermuda grass as well as many small-seeded annuals.

Cover crop allelopathy can hurt some vegetables as well, particularly small seeded crops that are direct sown too soon after the cover crop. Lettuce seedlings are especially sensitive to allelochemicals, while large-seeded and transplanted vegetables are generally more tolerant. Tomatoes and other solanaceous vegetables thrive when transplanted through recently-killed residues of rye and/or hairy vetch (Smeda and Weller, 1996). Winter grain cover crop residues have been reported to reduce growth of cabbage, but to stimulate peas, beans, and cucumbers (Putnam and DeFrank, 1983; Putnam et al., 1983).

Unlike direct competition, allelopathic weed suppression can persist for a few weeks after a cover crop is terminated. Tilling the top growth in as a green manure causes an intense but relatively brief burst of allelopathic activity throughout the till depth. Leaving the residues on the surface as an *in situ* mulch creates a shallow (less than one inch) but more persistent allelopathic zone that can last for three to ten weeks depending on weather conditions. Thus no-till cover crop management offers a potential for selective suppression of small-seeded annual weeds in transplanted and large-seeded vegetables, whose roots grow mostly below the allelopathic zone.

In addition to this "selectivity by position," some allelochemicals may be inherently selective toward larger seeds. In petri dish germination tests, green pea seeds (large) were far more tolerant to low (1–5 ppm) concentrations of various isothiocyanates than redroot pigweed seeds (small), with barnyard grass seeds (medium) showing intermediate sensitivity (Al-Khatib et al., 1997). Similar selectivity has been observed in field studies, on vegetables grown after brassica cover crops. Whereas the weed suppressive effects of the cover crops persisted for at least part of the vegetable growing season, yields were either unaffected or improved in potatoes (Boydston and Hang, 1995), peas, spinach (direct-sown), onions (from sets), and transplanted lettuce (Al-Khatib et al., 1997; Schonbeck, 2007).

Weed Seed Germination

While a brief flash of unfiltered daylight, or even a few minutes of full moonlight, can trigger germination of many small-seeded weeds, the green light that reaches the soil beneath a closed canopy of plant foliage tends to inhibit germination (Fig. 4). This is because many seeds sense the quality of light by means of a special compound called phytochrome that works as a molecular switch. Red light (abundant in daylight) flips the switch to “germinate now” whereas light that is poor in red and rich in far-red (a wavelength between red and infrared, barely visible to the human eye) flips the switch to “go dormant”. The chlorophyll in green leaves absorbs most of the red light and transmits the far-red, and the phytochrome in weed seeds senses the filtered light as a signal that a shading canopy is present, rendering conditions unfavorable to weed growth. Part of the weed-suppressive effects of hairy vetch cover crops have been attributed to this light quality effect

(Teasdale and Daughtry, 1993). This phenomenon may also contribute to the weed suppression sometimes observed after other dense-canopy cover crops like buckwheat (Fig. 1) or radish (Fig. 3).

Figure 4. This year-old stand of red clover casts dense shade and alters the quality of light reaching the ground so that seeds of most annual weeds are no longer stimulated to germinate. Several field studies have documented a decline in annual weed populations in cultivated fields that are rotated to red clover for one or more years. With few or no annual weeds growing and replenishing the weed seed bank, weed seed numbers decline through seed predation, physiological aging, and decay. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Effects on Soil Microbial Communities

Each plant species exudes through its roots a characteristic mix of substances, including carbohydrates, amino acids, organic acids, and other "microbial food", as well as its particular set of allelochemicals. This biochemical mix elicits and supports a specific **microflora** (community of fungi, bacteria, protozoa, and other microorganisms) in the plant's rhizosphere (the soil immediately adjacent to the plant roots); to a lesser degree, it also influences the microflora of the bulk soil. The microbes fostered by one plant species can help, hinder, or even sicken another plant species.

A vigorous cover crop with an extensive root system that harbors microorganisms harmful to certain weeds can thereby provide an added measure of control of those weeds. For example, most grain and legume cover crops are strong hosts for mycorrhizal fungi which live as root symbionts and enhance crop growth. Several major weeds, including pigweeds, lambsquarters, nutsedges, purslane, and weeds in the buckwheat family, are nonhosts that do not benefit from mycorrhizae, and may exhibit reduced vigor if their roots are invaded by mycorrhizal fungi (Francis and Read, 1995; Muthukumar et al., 1997). Several researchers have begun to explore the potential of mycorrhizal fungi as a weed management tool (Jordan et al., 2000; Vatovec et al., 2005).

Plant root exudates and plant-microbe interactions can also influence certain species or classes of microorganisms in the soil as a whole, with subsequent effects on other plants. For example, the glucosinolates and isothiocyanates released by crops and weeds in the crucifer family (such as brassica crops, wild mustards, and yellow rocket) can inhibit soil fungi, including some pathogens (Haramoto and Gallandt, 2004). Crucifers and other nonmycorrhizal host plants, while not directly toxic to mycorrhizae, do not support the high populations of active mycorrhizal fungi often found in the soil after strong-host species such as most legumes.

Crop–weed–soil–microbe interactions are one of the cutting edges in organic weed management research. Scientists are searching for specific microbial species or floras that thrive in the root zone of widely-used cover crops, and that attack or suppress major weed species without posing a serious threat to the desired vegetable crops. These relationships are complex, and practical applications are some years or decades away.

Mulch Effect

When a cover crop is killed by temperature extremes, mowing, or rolling, residues left on the soil surface as a mulch can continue to hinder weed growth for some time. By keeping the soil surface shaded and cool, and by reducing daily fluctuations in soil temperature, the organic mulch reduces the number of weed seeds that are triggered to germinate. Small-seeded broadleaf weeds that do sprout are often effectively blocked by a 2–3 inch thick layer of cover crop residues. Larger-seeded broadleaf seedlings, grass seedlings, and perennial weed shoots from buried rhizomes and tubers will eventually get through, though even their growth may be delayed by residues of a high biomass cover crop.

The mulch effect can be enhanced by the release of allelopathic substances from the decaying residues, as noted earlier. In addition, organic mulch provides habitat for ground beetles and other predators of weed seeds, as well as microorganisms that can attack and kill weed seedlings.

Weed suppression by cover crop residue can vary from negligible to highly effective for anywhere from two weeks to several months (Fig. 5), depending on cover crop biomass and nitrogen (N) content, season, weather, and soil conditions. Warm, moist weather combined with high soil biological activity accelerates decomposition of cover crop residues and their allelochemicals, thus shortening the weed control period. Strawy, low-N residues last longer than succulent, high-N residues. In dry climates, the weed suppressive effect of even a legume cover crop mulch can be substantial (Hutchinson and McGiffen, 2000).

Figure 5. This rye–vetch cover crop mulch delayed weed growth sufficiently to prevent significant weed competition against the broccoli. The mulch effect effectively blocked most annual weeds, while a few perennial quack grass are beginning to break through. The cover crop was mowed and the broccoli transplanted about seven weeks before this picture was taken on Cape Cod, MA. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Green Manure Effects

Tilling a cover crop into the soil as a green manure stimulates a flush of microbial activity that can make the soil temporarily inhospitable to most weeds and crops. The tillage itself stimulates weed seed germination, but the incorporated residues may promote damping-off fungi and other pathogens that then attack the weed seedlings (Kumar et al., 2008). If the residues are rich in carbon (C) relative to N (C:N ratios of 30 or higher), soil microbes will immobilize (tie up) plant-available soil N while consuming the C-rich organic matter, and thereby slow the growth of weed seedlings. These effects—combined with the brief intense flush of allelochemicals from certain cover crops, especially radish and other brassicas—can help clean up a weedy field.

On the other hand, leguminous or young, succulent green manures (Fig. 6) provide plenty of N and other nutrients that can stimulate a burst of weed emergence and growth, thereby negating earlier weed-suppressive effects of the cover crop.

Figure 6. A farmer on Cape Cod, MA plows down a winter cover crop of hairy vetch in late spring. The succulent, high-nitrogen legume cover crop will decompose rapidly and require only a short (one to two week) waiting period before vegetables can be planted. The disadvantage to this practice is that it may also open a highly fertile niche for weed growth. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Note that cash crops are also subject to green manure effects. Vegetables should not be planted during the microbial flush after soil incorporation of a green manure. Careful timing is essential to avoid adverse effects of green manure on vegetables, yet take advantage of temporary weed-suppressive effects that can give the vegetable a head start on the weeds.

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables**. For more information on the use of cover crops in weed management, see:

- **Plant and Manage Cover Crops for Maximum Weed Suppression**
- **What is “Organic No-till,” and Is It Practical?**

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Plant and Manage Cover Crops for Maximum Weed Suppression

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Introduction

A cover crop planted correctly and managed well can give nearly 100% weed control while it is growing, and substantial weed management benefits in subsequent vegetables. However, a cover crop poorly managed can become a weedy mess and make a huge deposit into the weed seed bank. Following are some tips for avoiding the pitfalls and maximizing your chances for success

1. Choose the right cover crop for the climate and the season (#1)
2. Be sure to use high quality seed (#2)
3. Prepare a good, weed-free seedbed (#3)
4. Use optimum seeding depths, adequate seeding rates, and good sowing technique (#4)
5. Take care of the cover crop; don't hesitate to water, feed, or lime if warranted (#5)
6. Feed the cover crop, not the weeds (#6)
7. Grow a cover crop to maturity if—and only if—it is a good stand (#7)

Choose the Right Cover Crop for the Climate and Season

Sow warm season, frost-tender cover crops like soybean, buckwheat (/article/18572) , and millet after the spring frost-free date and at least six to eight weeks before the fall frost date to ensure rapid growth and good biomass production. Cowpea (Fig. 1), sorghum–sudangrass (/article/18541) , and most millets require really warm soil—at least 65–70°F. They may establish slowly and become weedy if sown immediately after the spring frost date when the soil is still cool, but they will grow rapidly and overwhelm most weeds if sown later when the soil and weather are really warm.

Figure 1. Cowpeas planted in June or July when the soil is thoroughly warm can look like this within five or six weeks after planting, even in fields with fairly heavy weed pressure such as this one. However, cowpeas planted just after the spring frost date, when the soil is still fairly cool, can emerge slowly and sporadically, giving weeds the upper hand. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Sow cool season crops like oats, field peas, bell beans, and forage radish (/article/18643) in early spring when cool moist soil conditions favor rapid growth. Plant winter annuals like cereal rye (/article/18571) (Fig. 2), wheat, winter barley, vetches, crimson clover, and Austrian winter peas at the end of summer or in early fall, giving them time to put on about 4–6 inches of growth before winter freezes render them dormant. Avoid planting any cool-weather cover crops at a time that will expose them to summer heat (daily highs of 85°F or more) before they approach full height. Heat retards their growth and lets summer annual weeds break through.

Figure 2. Winter rye (cereal rye) can be planted as late as November 1 in hardiness zone 7 and still give a fairly good stand like this by late April. However, bicultures of winter rye with winter annual legumes like hairy vetch should be planted about a month earlier so that the legume can get established sufficiently to overwinter well. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Be Sure to Use High Quality Seed

Even a day's delay in cover crop establishment that results from weaker seed can give the weeds a chance to get a foothold. Patchy stands from poor quality seed can defeat the purpose of cover cropping altogether (Fig. 3).

Figure 3. In this cover crop variety trial, one seed lot of forage soybean was of poor vigor and gave a spotty stand (a). Forage soybeans from good seed yielded a high biomass, nearly weed-free stand (b), whereas the low vigor seed gave a weedy stand (c). Figure credits: Mark Schonbeck, Virginia Association for Biological Farming.

Use current-year seed from a reputable source for cool season cereal grains, buckwheat (/article/18572) , and soybeans. High quality pea, bell bean, cowpea, millet, and sorghum–sudangrass (/article/18541) seed that is properly stored (kept cool and dry) can be used for two or three years; vetches and clovers can last up to five years. When in doubt, get new seed.

Prepare a Good, Weed-free Seedbed

Be sure to remove weed competition before sowing a cover crop. In addition to removing top growth of any existing weeds, seedbed preparation should include chopping up or otherwise disrupting the rhizomes, rootstocks, and other belowground structures of of perennial weeds. Also, be sure that thousands of weed seeds are not germinating just below the surface when you plant the cover crop. The final shallow tillage to finish the seedbed should take place minutes or hours—not days—before planting. Planting into an apparently clean seedbed prepared two to five days earlier can result in a weedy cover crop (Fig. 4). Broadcast seeding followed by shallow tillage to incorporate the seed is one way to knock out weed seedlings in the white thread stage and plant the cover crop in one pass.

Figure 4. Never drill a cover crop into a seedbed that was prepared several days earlier, regardless of how clean it looks, unless you are prepared to flame-weed or rotary hoe before the crop emerges. This seedbed, prepared five days prior to this photograph, looked fairly "clean" at a glance (a), but light stirring of the soil surface reveals numerous tiny weed seedlings in the white thread stage (b). Cover crops, including the vigorous forage soybean shown here, became infested with weeds when planted in a seedbed prepared five days before planting (c). Figure credits: Mark Schonbeck, Virginia Association for Biological Farming.

Work the soil surface sufficiently to give good seed–soil contact. Usually, it is not necessary to pulverize the soil to sow a cover crop, and such rough treatment is bad for soil quality. If weed pressure is minimal and crop residues are not too heavy, no-till planting with a good no-till drill can give sufficient seed–soil contact.

Use Optimum Seeding Depths, Adequate Seeding Rates, and Good Sowing Technique

Cover crop–weed competition is a race that you want the cover crop to win! Remember that most cover crops emerge as large seedlings—many times larger than most weeds, which gives them an initial advantage. However, weed seedlings double their size in fewer days than large seeded crops, and will begin closing the gap—unless and until they are shaded out by cover crop canopy closure. A heavy, even stand is essential. Individual cover crop seedlings should be fairly uniformly distributed across the field, and close enough together so that they will intercept most of the incident light and their roots will occupy most of the soil volume within a few weeks after planting (Fig. 5).

Figure 5. This rye–hairy vetch cover crop was skillfully broadcast by Virginia farmer Charlie Maloney using a manually operated spin seeder. Immediately after broadcasting, he rototilled shallowly to incorporate the seeds into the top inch, simultaneously knocking out any newly-germinated weeds. Any later-emerging weeds will have little chance in this dense, uniform cover crop stand, photographed here 11 days after planting. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

Use recommended seeding depths for each cover crop species. In warm, dry conditions, go a little deeper (up to 50% deeper); in cool wet conditions go a bit less deep. Planting large seeded crops too close to the surface, or small seeded crops too deep, can result in poor stands.

Be sure to plant enough seed! Never try to stretch cover crop seed by sowing at lower than recommended rates. Increase rates to 1.5, 2, or even 3 times recommended rates (if economically feasible) when weed pressure is heavy; when soil fertility, seedbed, or planting dates are not quite optimum; or when seed quality may not be optimum or germination percentages are below 85%.

Watch these video clips from an organic vegetable farm in Plainfield, NH (Grubinger, 2004) for examples using high seeding rates for **buckwheat** (http://www.extension.org/pages/Video_Clip:_Summer_Cover_Crop:_Buckwheat_from_Vegetable_Farmers_and_ and **Japanese millet** (http://www.extension.org/pages/Video_Clip:_Summer_Cover_Crop:_Japanese_Millet_from_Vegetable_Farmers_ to produce excellent smother crops.

Use good sowing technique for uniform stands. Broadcasting seeds evenly with a manually operated or tractor mounted spin seeder, followed by shallow incorporation to the desired depth with rotary tiller, harrow, or other implement, can give the most uniform stands that rapidly shut out weeds (Fig. 5). Drilling in closely spaced rows (5–6 inches apart) is a close second. Simply broadcasting seed on the soil surface can lead to thin or patchy stands, unless good rains or diligent irrigation keep the seed moist until the crop is established, and seed-eating birds and ground beetles are scarce. For overseeding cover crops into standing vegetables, either use a drill or multirow push seeder between rows, or broadcast seed just prior to the last cultivation for weed control, which will also incorporate the cover crop seeds.

Take Care of the Cover Crop; Don't Hesitate to Water, Feed, or Lime if Warranted

While cover crops are less fussy than most vegetables, they do need water, nutrients, and reasonable soil tilth and pH (acidity) to grow vigorously and get the jump on weeds.

If the soil is dry and it is at all feasible to water a newly-planted cover crop, do it! One sprinkler irrigation may be all it takes to get a drought-tolerant summer cover crop like cowpea, sunnhemp, millet, or sorghum–sudangrass (/article/18541) established. Most cool season cover crops are less drought hardy and depend on spring or fall rains to thrive. End-of-summer plantings of oat, field pea, and/or bell bean may be particularly difficult to establish in dry seasons; try barley, radish, or mustards (/article/18643) instead.

If a subsurface hardpan is present, break it with a chisel plow or subsoiler before planting a cover crop. A severe hardpan will even block sweetclover and radish roots, reduce cover crop vigor, and favor those weeds that tolerate compaction. If the hard layer is fractured before planting, cover crop roots can penetrate and open the soil profile for future cash crops.

If soil pH is very low (acid—5.5 or lower) or high (alkaline—8.0 or higher), apply limestone or acidifying amendments, respectively. Since limestone takes a year or two to correct acid soil pH, start with acid-tolerant cover crops like oat, buckwheat (/article/18572) , cereal rye (/article/18571) , hairy vetch (/article/18570) , and cowpea. Barley, brassica family (/article/18643) , sweetclover, and woolypod vetch do well on somewhat alkaline soils.

It may be appropriate to spread aged manure, compost, and/or slow-release organic fertilizer before planting a cover crop. Make sure that the materials to be used do not carry a lot of weed seeds. Feeding a cover crop is an excellent way to use manure that has not been hot-composted in certified organic operations, which require a 120-day interval between manure application and vegetable harvest. The cover crop takes up the nutrients, and both the cover crop and the amendments contribute to soil humus and nutrient levels at the time of the next vegetable planting.

On lower-fertility soils, be sure to provide organic sources of nitrogen, phosphorus, and potassium (NPK) for heavy-feeding cover crops like sorghum, sorghum–sudangrass (/article/18541) , radish, and wheat. Well-fed sorghum–sudangrass can reach a height of nine feet in 75 days and smother weeds, whereas underfed sorghum–sudangrass is thin, yellowish, and weed-infested at the same age. Buckwheat (/article/18572) , pearl, and foxtail millets are somewhat more tolerant to lower soil fertility levels, while cowpea, sunnhemp, cereal rye (/article/18571) , and hairy vetch (/article/18570) can be considerably more so. However, when soil fertility is low, all cover crops respond to compost and other slow-release nutrient sources with increased vigor, higher biomass, and better weed suppression.

Legumes can derive most of their own N through symbiotic root nodule bacteria (*Rhizobium* or *Bradyrhizobium*)—provided that the right bacteria are present! Use the correct seed inoculant for each legume cover crop to be sure that its N-fixing capacity is realized. Proper nodulation enhances legume competitiveness against weeds, especially when soil soluble N levels have been drawn down by heavy feeding cash crops. Vigorous, well-nodulated legumes also form strong associations with mycorrhizal fungi that enhance uptake of P, micronutrients, and moisture.

Feed the Cover Crop, Not the Weeds

One important caution about fertilizing cover crops: *fresh* manure and other materials that rapidly release a lot of soluble nutrients can compromise the cover crop's ability to outcompete weeds. Liebman and Gallandt (1997) point out that, in soils with fairly low levels of soluble N (especially nitrate), N-fixing legume cover crops have a big advantage over most weeds and they can effectively shade them out. With high soluble N levels, this advantage is lost, and the weeds may gain the upper hand. In addition, fresh manure is itself often a major source of weed seeds.

Slow-release sources such as high quality compost are more likely to support vigorous cover crops without speeding the growth of nutrient-responsive weeds. If a "hot" material like fresh manure or chicken litter is the only organic fertility source available for restoring depleted soil, follow its application immediately with a nonlegume cover crop that can rapidly take up and stabilize the soluble N and outrun the weeds. Examples include cereal rye (/article/18571) , radish (/article/18643) , sorghum–sudangrass (/article/18541) , and pearl millet.

Get a soil test from a competent lab to check nutrient levels before applying manure or compost, especially when restoring soils with a long history of conventional farming. A "dead" soil with little organic matter may also be nutrient-depleted, or it may actually have high or excessive P and K levels depending on past fertilizer applications. On a biologically-depleted soil with very high P and K, avoid manure applications and plant legume or legume–grass cover crops to suppress weeds, replenish N, and rebuild soil quality. Light applications of high quality compost or vermicompost (worm castings), or the application of compost tea or biodynamic field sprays, can reintroduce beneficial soil organisms that help rebuild soil quality. Soil tests can also help detect micronutrient deficiencies or pH extremes that might limit cover crop growth and favor those weeds that are adapted to these conditions.

Grow a Cover Crop to Maturity If—and Only If—it is a Good Stand

In order to gain the maximum benefits from a cover crop, grow it to maturity—full height, full heading with pollen shed in grains and grasses, and full bloom in legumes and other broadleaf crops. Prevent the cover crop from self-seeding by terminating it before seed or pod formation, unless a second generation of cover crop through self-seeding is desired. Growing the cover crop to the flowering/heading stage before terminating it maximizes biomass production and—in legumes—nitrogen fixation, prolongs and maximizes weed suppression and soil protection, provides extended habitat for beneficial insects, and—in the case of grass–legume bicultures—optimizes the C:N ratio for humus formation and slow-release of nutrients to the next crop.

A few weeds in a healthy, dense stand of cover crop will likely be outcompeted, and are usually not a reason to terminate the crop early (Fig. 6). However, if the cover crop stand is thin, uneven, and/or quite weedy (see the third photo in Fig. 4 for an example), the crop should be terminated before weeds have a chance to set seed or propagate through rhizomes, tubers, and other vegetative structures. Timely mowing can postpone seed formation by annual weeds, and can be used to extend the cover crop period if the field is not infested with perennial weeds that reproduce vegetatively.

Figure 6. These young cover crops of sorghum–sudangrass and lablab bean (a tropical legume suitable for warm humid climates in the southeastern US) are sufficiently dense and uniform to compete effectively against the few weeds emerging with them. This stand should be allowed to grow until the grass begins to head in order to derive the maximum benefit. Mowing sorghum–sudangrass back to a stubble height of about one foot and letting it regrow has been reported to stimulate additional rooting, which could further enhance its weed suppressive effects. Figure credit: Mark Schonbeck, Virginia Association for Biological Farming.

This article is part of a series on **Twelve Steps Toward Ecological Weed Management in Organic Vegetables** (/article/18539) . For more information on the use of cover crops in weed management, see:

- **How Cover Crops Suppress Weeds** (/article/18524) (/article/18525)
- **What is "Organic No-till," and Is It Practical?** (/article/18526)
- **Video: Vegetable Farmers and their Innovative Cover Cropping Techniques** (http://www.extension.org/article/18439)

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University of Connecticut INTEGRATED PEST MANAGEMENT IPM

CONTRIBUTION OF COVER CROP MULCHES TO WEED MANAGEMENT

Weed suppression is one of the important contributions cover crops can provide for cropping systems. Two types of cover crops will be discussed: winter annual cover crops that typically provide a mulch of cover crop residue after being killed when the summer crop is planted and living mulches that grow during part or all of the crop growing season. Winter annual cover crops have been most successfully incorporated into crop rotations and are most widely used to date. Living mulches often compete excessively with the crop and have received attention mostly from researchers to date.

Weed Control by Cover Crop Residue

The degree of weed control provided by cover crops can vary according to cover crop species, residue quantity, and weed species.

Research has demonstrated that:

1. weed suppression by cover crop residue increases with increasing residue quantity - natural levels of typical cover crop residues can be expected to reduce weed emergence by 75 to 90%,
2. weed suppression will decline during the course of the season according to the rate of residue decomposition,
3. residues with a large number of layers and small amount of empty internal space will be most suppressive, and
4. annual species that are small-seeded and have a light requirement for germination such as common lambsquarters and pigweeds are sensitive to surface residue whereas large-seeded annuals and perennial weeds are relatively insensitive.

Practical application of these results suggest that best weed control can be obtained by:

1. using cover crops that produce high amounts of biomass,
2. using cover crops that do not decompose rapidly,
3. using cover crop management implements that pack or compress the mulch, and
4. avoid fields with high populations of perennial or large-seeded annual weeds.

Generally, cover crop residue can be expected to provide early-season weed suppression but not full-season weed control. As a result, cover crops can contribute to weed control in reduced-tillage systems but herbicides or other weed control tactics are required for achieving optimum weed control and crop yield. However, cover crops can permit a reduction of herbicide inputs and a shift toward total postemergence herbicide programs. Early weed suppression provided by cover crop residue should permit crops to become established before weeds. Postemergence herbicides can control later-emerging weeds until the crop has grown past the critical period for weed control. This approach could reduce herbicide losses to the environment by replacing preemergence herbicides that are frequently detected in ground and surface waters with postemergence herbicides that are used at lower rates and are less persistent.

Factors Influencing Weed Emergence through Cover Crop Residue

The formation of a **physical barrier** by cover crop residue is an important factor that can prevent emergence of weed seedlings. But residue also influences the microclimate of the soil by intercepting incoming radiation. Interception and reflection of short-wave radiation by mulch elements reduce the quantity of light available to the soil surface, the heat absorbed by soils during the day, and the amount of soil moisture evaporated from soils. These effects can interact with a multitude of seed germination requirements to determine the pattern of weed seedling emergence observed in any given season.

Light transmittance to the soil surface declines exponentially with increasing residue biomass. Many weed species require light to activate a phytochrome-mediated germination process prior to emergence. Emerging weeds also require light for initiation of photosynthesis before seed reserves are depleted. Extinction of light by residue can be an important factor inhibiting weed emergence through residue; in fact, weed suppression is highly correlated with light extinction.

Light transmittance through cover crop residue is highly heterogeneous despite the appearance of uniform soil coverage. Natural rates of hairy vetch or rye residue may have up to 60% of sites transmitting more than 10% of incoming radiation whereas twice the natural residue rate may still permit up to 25% of sites transmitting more than 10% of incoming radiation. These sites that transmit a high fraction of radiation may explaln why complete weed control often is not obtained by a seemingly uniform layer of residue.

Natural residue levels on the soil surface can reduce maximum soil temperature by 2 to 5°C and raise minimum soil temperature by 1°C in temperate climates although this will vary according to radiation intensity, soil moisture, and soil type. Most weed seed will germinate over a wide range of temperatures and, therefore, the degree of reduction in maximum soil temperature by residue is not sufficient to prevent germination. However, reduced maximum soil temperatures may delay the emergence of many species. Because of the decrease in maximum and increase in minimum soil temperature, **soil temperature amplitude** is reduced by residue. High temperature amplitudes often are required to break the dormancy of selected weed species and, therefore, a reduction in soil temperature amplitude by cover crop residue can prevent germination of weed species with this requirement.

Residue on the soil surface increases **soil moisture** by increasing infiltration of rainfall and by decreasing evaporative moisture loss. Higher soil moisture under cover crop residue could either benefit or retard weed germination depending on species requirements. Under saturated soil conditions, residue could slow evaporation and reduce germination of species inhibited by excess soil moisture. Under droughty conditions, retention of soil moisture could enhance weed germination and seedling survival.

Chemical compounds released from cover crop residue have potential to stimulate or inhibit weed germination and growth. **Nitrates** released by legume residue can stimulate germination of selected weed species. On the other hand, research has demonstrated the presence of toxins known as **allelochemicals** that inhibit germination and growth of many weed species. In natural environments it is difficult to separate allelopathic effects from the physical effects described above. It also can be difficult to determine whether growth inhibition by residues with high carbon/nitrogen ratios is due to allelopathy or immobilization of nitrogen.

Living Mulches

There are many approaches to incorporating living mulches into cropping systems. A few examples of living mulches include perennial sod-like mulches that are maIntained for many years once established, a cover crop into which the cash crop is relay planted, and a cover crop overseeded into a cash crop. Generally, living mulches can suppress weeds if they are well-established before emergence of weeds and maintain uniform coverage of the soil; that is, if they become occupants of the niche normally occupied by weeds. In almost every case where living mulches are competitive enough to successfully displace weeds, they also are competitive enough to reduce crop growth and yield as well.

Several approaches have been taken to minimize the impact of living mulches on crop productivity:

1. broadcast suppression of the living mulch with a sublethal herbicide dose,
2. band-killing the living mulch within the crop row with a lethal herbicide dose,
3. strip-tillage within the crop row,
4. increasing the competitiveness of the crop through manipulation of the population and plant spacing, and
5. providing sufficient nutrients and water to compensate for resources used by the living mulch.

Successful Approaches to Using Cover Crops for Vegetable Production

Hairy vetch has been demonstrated to be a valuable cover crop for both agronomic and vegetable crops. A hairy vetch cover crop that is planted in fall will consistently produce high biomass with a high nitrogen content in most areas of the country except the extreme north. This cover crop can be easily killed by herbicide, mowing, or rolling in the spring to leave a uniform mulch on the soil surface which will reduce erosion, suppress weeds, and release nitrogen. Growing fresh-market tomatoes in hairy vetch residue can reduce herbicide and nitrogen inputs and eliminate the cost of installing and disposing of plastic mulches. Because of sizable yield increases and cost reductions, this system has provided substantial increases in economic returns. This system is most applicable to vegetable crops with postemergence herbicides registered for control of both broadleaved and grass weeds.

Although hairy vetch has many benefits, it has weaknesses as well. Hairy vetch captures very little excess nutrient in soils during fall and winter months. It also suppresses weeds for only a limited period of time because of rapid decomposition. **Rye** has many characteristics that are the opposite of hairy vetch. Rye is superior at capturing nutrients in fall and winter and provides a more persistent weed suppressive mulch in summer. However, a rye cover crop can remove excess soil moisture and can immobilize nitrogen if left to grow too long in spring; yield losses in corn and tomatoes often are observed in this situation.

A mixture of hairy vetch and rye can provide a broader spectrum of benefits than either cover crop alone. We have observed higher mulch biomass and improved weed control by this mixture than by either species alone. The carbon:nitrogen ratio of the mixture remains low enough to prevent nitrogen immobilization as long as the rye component is seeded below monoculture seeding rates (a seeding rate of 40 lb/A of vetch plus 40 lb/A of rye has been effective in our research). Cover crop mixtures have proven to be an effective means of increasing the weed suppressive capability of cover crops as well as maintaining many of the other benefits of both species.

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Information on our site was developed for conditions in the Northeast. Use in other geographical areas may be inappropriate.

menu

Overview of Cover Crops and Green Manures

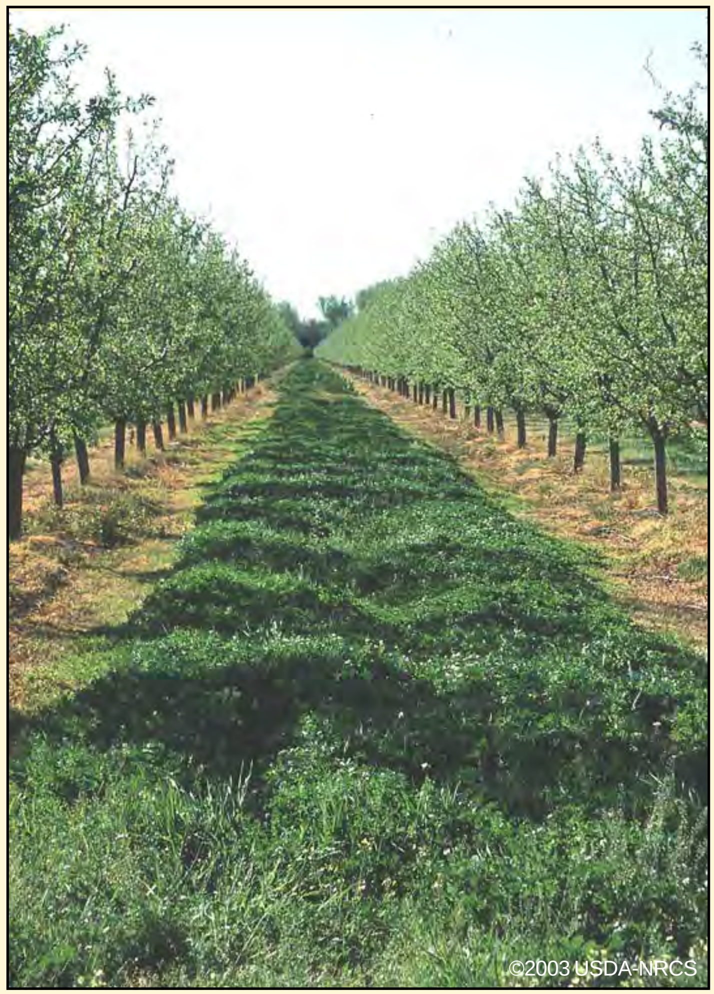
Fundamentals of Sustainable Agriculture

Abstract: *Cover crops could be considered the backbone of any annual cropping system that seeks to be sustainable. In this publication we summarize the principal uses and benefits of cover crops and green manures. Brief descriptions and examples are provided for winter cover crops, summer green manures, living mulches, catch crops, and some forage crops. To impart a sense of the importance of these practices in sustainable farming, we summarize the effect of cover crops and green manures on: organic matter and soil structure, nitrogen production, soil microbial activity, nutrient enhancement, rooting action, weed suppression, and soil and water conservation. Management issues addressed include vegetation management, limitations of cover crops, use in crop rotations, use in pest management, and economics of cover crops. A selection of print and Web resources are provided for further reading.*

By Preston Sullivan
NCAT Agriculture Specialist
July 2003

Introduction

Cover crop information abounds. In the past ten years, the number of research reports, Extension bulletins, Experiment Station reports, and popular press articles on cover crops has increased dramatically. For example, the third quarter 1998 issue of *The Journal of Soil and Water Conservation* contains 17 research reports on cover crops. Several excellent field handbooks have also been written. Consequently, rather than attempting to address that large body of information, this publication serves as an overview of cover crops and their uses and provides a resource list. The resource list gives ordering instructions and prices for readers who want current information in more detail.



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Principal Uses of Cover Crops and Green Manures

"Green manuring" involves the soil incorporation of any field or forage crop while green or soon after flowering, for the purpose of soil improvement. A cover crop is any crop grown to provide soil cover, regardless of whether it is later incorporated. Cover crops are grown primarily to prevent soil erosion by wind and water. Cover crops and green manures can be annual, biennial, or perennial herbaceous plants grown in a pure or mixed stand during all or part of the year. In addition to providing ground cover and, in the case of a legume, fixing nitrogen, they also help suppress weeds and reduce insect pests and diseases. When cover crops are planted to reduce nutrient leaching following a main crop, they are often termed "catch crops."

Winter cover crop

A winter cover crop is planted in late summer or fall to provide soil cover during the winter. Often a legume is chosen for the added benefit of nitrogen fixation. In northern states, the plant selected needs to possess enough cold tolerance to survive hard winters. Hairy vetch and rye are among the few selections that meet this need.

Many more winter cover crops are adapted to the southern U.S. These cool-season legumes include clovers, vetches, medics, and field peas. They are sometimes planted in a mix with winter cereal grains such as oats, rye, or wheat. Winter cover crops can be established by aerial seeding into maturing cash crops in the fall, as well as by drilling or broadcasting seed immediately following harvest.

Summer green manure crop

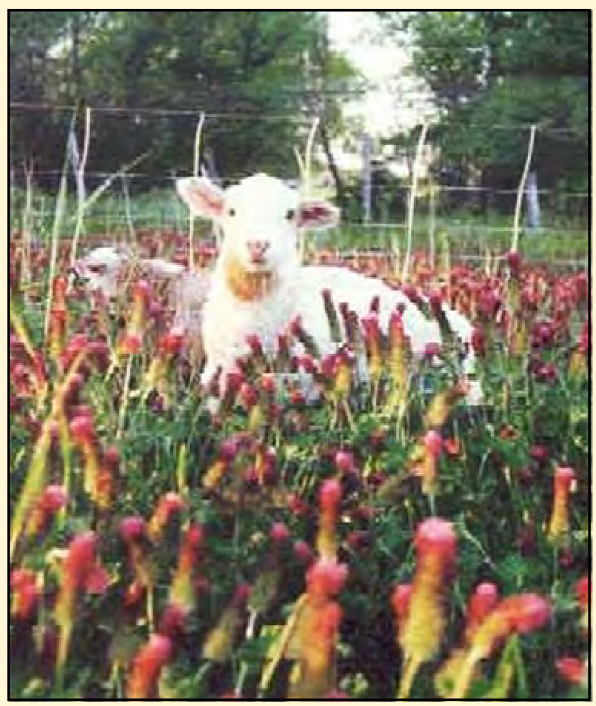
A summer green manure occupies the land for a portion of the summer growing season. These warm-season cover crops can be used to fill a niche in crop rotations, to improve the conditions of poor soils, or to prepare land for a perennial crop. Legumes such as cowpeas, soybeans, annual sweetclover, sesbania, guar, crotalaria, or velvet beans may be grown as summer green manure crops to add nitrogen along with organic matter. Non-legumes such as sorghum-sudangrass, millet, forage sorghum, or buckwheat are grown to provide biomass, smother weeds, and improve soil tilth.

Living mulch

A living mulch is a cover crop that is interplanted with an annual or perennial cash crop. Living mulches suppress weeds, reduce soil erosion, enhance soil fertility, and improve water infiltration. Examples of living mulches in annual cropping systems include overseeding hairy vetch into corn at the last cultivation, no-till planting of vegetables into subclover, sweetclover drilled into small grains, and annual ryegrass broadcast into vegetables. Living mulches in perennial cropping systems are simply the grasses or legumes planted in the alleyways between rows in orchards, vineyards, Christmas trees, berries, windbreaks, and field nursery trees to control erosion and provide traction.

Catch crop

A catch crop is a cover crop established after harvesting the main crop and is used primarily to reduce nutrient leaching from the soil profile. For example, planting cereal rye following corn harvest helps to scavenge residual nitrogen, thus reducing the possibility of groundwater contamination. In this instance, the rye catch crop also functions as a winter cover crop. Short-term cover crops that fill a niche within a crop rotation are also commonly known as catch crops.



Forage crop

Short-rotation forage crops function both as cover crops when they occupy land for pasturage or haying, and as green manures when they are eventually incorporated or killed for a no-till mulch. Examples include legume sods of alfalfa, sweet clover, trefoil, red clover, and white clover, as well as grass-legume sods like fescue-clover pastures. For maximum soil-improving benefits, the forage should not be grazed or cut for hay during its last growth period, to allow time for biomass to accumulate prior to killing.

Benefits of Cover Crops and Green Manures

Organic matter and soil structure

A major benefit obtained from green manures is the addition of organic matter to the soil. During the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition—such as gums, waxes, and resins. These compounds—and the mycelia, mucus, and slime produced by the microorganisms—help bind together soil particles as granules, or aggregates. A well-aggregated soil tills easily, is well aerated, and has a high water infiltration rate. Increased levels of organic matter also influence soil humus. Humus—the substance that results as the end product of the decay of plant and animal materials in the soil—provides a wide range of benefits to crop production.

Sod-forming grass or grass-legume mixtures are important in crop rotations because they help replenish organic matter lost during annual cultivation. However, several years of sod production are sometimes required before measurable changes in humus levels occur. In comparison, annual green manures have a negligible effect on humus levels, because tillage and cultivation are conducted each year. They do replenish the supply of active, rapidly decomposing organic matter (1).

The contribution of organic matter to the soil from a green manure crop is comparable to the addition of 9 to 13 tons per acre of farmyard manure or 1.8 to 2.2 tons dry matter per acre (2).

Table 1 shows dry matter production of several winter-annual legume cover crops grown in the southern U.S. Approximately 2.2 tons per acre per year of crop residue is considered adequate to maintain soil organic matter at constant levels in continuously cropped soils (3). This figure will vary according to climate, region, and cropping system.

Table 1. Average biomass yields and nitrogen yields of several legumes (4).

Cover Crop	Biomass	Nitrogen
	Tons/acre	Lbs./acre
Sweet clover	1.75	120
Berseem clover	1.1	70
Crimson clover	1.4	100
Hairy vetch	1.75	110

Nitrogen production

Nitrogen production from legumes is a key benefit of growing cover crops and green manures. Nitrogen accumulations by leguminous cover crops range from 40 to 200 lbs. of nitrogen per acre. The amount of nitrogen available from legumes depends on the species of legume grown, the total biomass produced, and the percentage of nitrogen in the plant tissue. Cultural and environmental conditions that limit legume growth—such as a delayed planting date, poor stand establishment, and drought—will reduce the amount of nitrogen produced. Conditions that encourage good nitrogen production include getting a good stand, optimum soil nutrient levels and soil pH, good nodulation, and adequate soil moisture.

The portion of green-manure nitrogen available to a following crop is usually about 40% to 60% of the total amount contained in the legume. For example, a hairy vetch crop that accumulated 180 lbs. N per acre prior to plowing down will contribute approximately 90 lbs. N per acre to the succeeding grain or vegetable crop. Dr. Greg Hoyt, an agronomist at North Carolina State University, has estimated that 40% of plant tissue nitrogen becomes available the first year following a cover crop that is chemically killed and used as a no-till mulch. He estimates that 60% of the tissue N is released when the cover crop is incorporated as a green manure rather than left on the surface as a mulch. Lesser amounts are available for the second or third crop following a legume, but increased yields are apparent for two to three growing seasons (5).

To determine how much nitrogen is contained in a cover crop, an estimate is needed of the yield of above-ground herbage and its percentage of nitrogen. A procedure to make this determination is available in the *Northeast Cover Crop Handbook*, in *Farmer's Fertilizer Handbook*, and in *Managing Cover Crops Profitably*. A description of these publications complete with ordering information can be found in the **Resources** section below.

The procedure involves taking a field sample, drying it, weighing it, and sending a sample off for forage analysis, which includes an estimate of protein content. Once the protein content is known, simply divide it by 6.25 to obtain the percentage of nitrogen contained in the cover crop tissue. Finally, to obtain pounds of legume nitrogen per acre, multiply the nitrogen figure by the pounds-of-biomass figure.

Forage legumes are valuable in rotations because they generate income from grazing or haying and still contribute nitrogen from regrowth and root residues. A high percentage of biologically fixed nitrogen is in the top growth (Table 2).

Table 2. Percent nitrogen in legume tops and roots (6).

Crop	Tops	Roots
	% N	% N
Soybeans	93	7
Vetch	89	11
Cowpeas	84	16
Red clover	68	32
Alfalfa	58	42

Soil microbial activity

A rapid increase in soil microorganisms occurs after a young, relatively lush green manure crop is incorporated into the soil. The soil microbes multiply to attack the freshly incorporated plant material. During microbial breakdown, nutrients held within the plant tissues are released and made available to the following crop.

Factors that influence the ability of microorganisms to break down organic matter include soil temperature, soil moisture, and carbon to nitrogen (C:N) ratio of the plant material. The C:N ratio of plant tissue reflects the kind and age of the plants from which it was derived (Table 3). As plants mature, fibrous (carbon) plant material increases and protein (nitrogen) content decreases (7). The optimum C:N ratio for rapid decomposition of organic matter is between 15:1 and 25:1 (6).

C:N ratios above 25:1 can result in nitrogen being "tied up" by soil microbes in the breakdown of carbon-rich crop residues, thus pulling nitrogen away from crop plants. Adding some nitrogen fertilizer to aid the decomposition process may be advisable with these high carbon residues. The lower the C:N ratio, the more N will be released into the soil for immediate crop use.

The C:N ratio is more a function of the plant's N content than its carbon content. Most plant materials contain close to 40% carbon. To determine the C:N ratio of any plant material, divide 40% by its nitrogen content. For example let's say hairy vetch contains 4.2% nitrogen: 40 / 4.2= a C:N ratio of 9.5. A procedure for determining the nitrogen content of cover crop biomass was previously addressed in the section on nitrogen production. Estimating the nitrogen contribution of a cover crop is very helpful when adjusting N-fertilizer rates to account for legume nitrogen.

Table 3 provides a nice comparison of the typical C:N ratios that can be found in different types of crop residues. The important point is that lush green manures are richer in nitrogen relative to carbon, especially in comparison to highly lignified crop residues like corn stalks. It will take a lot longer for soil microbes to break down corn stalks than fresh hairy vetch.

Table 3. Common C:N ratios of cover crops.

Organic Material	C:N Ratio	Reference
Young rye plants	14:1	4
Rye at flowering	20:1	4
Hairy vetch	10:1 to 15:1	8
Crimson clover	15:1	6
Corn stalks	60:1	4
Sawdust	250:1	9

Nutrient enhancement

In addition to nitrogen from legumes, cover crops help recycle other nutrients on the farm. Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and other nutrients are accumulated by cover crops during a growing season. When the green manure is incorporated, or laid down as no-till mulch, these plant-essential nutrients become slowly available during decomposition. Dr. Greg Hoyt developed a method for estimating nutrient accruement by cover crops in order to reduce the soil test recommendation of fertilizer for the following crop (10). Table 4 shows the biomass and nutrients accumulated by several cover crops he worked with.

Table 4. Biomass yield and nutrient accruement by selected cover crops (10).

Crop	Biomass* lbs/ac	Nitrogen lbs/ac	Potassium lbs/ac	Phosphorus lbs/ac	Magnesium lbs/ac	Calcium lbs/ac
Hairy Vetch	3,260	141	133	18	18	52
Crimson clover	4,243	115	143	16	11	62
Austrian W. P.	4,114	144	159	19	13	45
Rye	5,608	89	108	17	8	22

*Dry weight of aboveground plant material.

Certain broad-leaved plants are noted for their ability to accumulate minerals at high concentrations in their tissue. For example, buckwheat, lupine, and sweetclover are noted for their ability to extract P from soils. Likewise, alfalfa and other deep-rooting green manures scavenge nutrients from the subsoil and translocate them upwards to the surface rooting zone, where they become available to the following crop.

The breakdown of green manures in soil influences mineral nutrient availability in another way. During decomposition of organic matter, carbonic and other organic acids are formed as a byproduct of microbial activity. These organic acids react with insoluble mineral rocks and phosphate precipitates, releasing phosphates and exchangeable nutrients (6).

Rooting action

The extensive root systems of some cover crops are highly effective in loosening and aerating the soil. In Australian wheat experiments, the taproots of a blue lupine cover crop performed like a "biological plow" in penetrating compacted soils (11). When cover crops are planted after a subsoiling treatment, they help extend the soil-loosening effects of the deep tillage treatment. The rooting depths of several green manures grown under average conditions are listed in Table 5.

Table 5. Typical rooting depths of several green manure crops (2).

Depth (feet)	Green Manure Crop
5 to 7	Red Clover, Lupine, Radish, Turnips
3 to 5	Common Vetch, Mustard, Black Medic, Rape
1 to 3	White Clover, Hairy Vetch

Weed suppression

Weeds flourish on bare soil. Cover crops take up space and light, thereby shading the soil and reducing the opportunity for weeds to establish themselves. The soil-loosening effect of deep-rooting green manures also reduces weed populations that thrive in compacted soils.

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

Providing weed suppression through the use of allelopathic cover crops and living mulches has become an important method of weed control in sustainable agriculture. Allelopathic plants are those that inhibit or slow the growth of other nearby plants by releasing natural toxins, or "allelochemicals." Cover crop plants that exhibit allelopathy include the small grains like rye and summer annual forages related to sorghum and sudangrass. The mulch that results from mowing or chemically killing allelopathic cover crops can provide significant weed control in no-till cropping systems. Living mulches suppress weeds during the growing season by competing with them for light, moisture, and nutrients.

Soil and water conservation

When cover crops are planted solely for soil conservation, they should provide a high percentage of ground coverage as quickly as possible. Most grassy and non-legume cover crops, like buckwheat and rye, fulfill this need well. Of the winter legumes, hairy vetch provides the least autumn ground cover because it puts on most of its above-ground growth in the spring. Consequently, it offers little ground cover during the erosion-prone fall and winter period. Sowing a mix of leguminous and grassy-type cover crops will increase the ground coverage, as well as provide some nitrogen to the following crop.

The soil conservation benefits provided by a cover crop extend beyond protection of bare soil during non-crop periods. The mulch that results from a chemically or mechanically killed cover crop in no-till plantings increases water infiltration and reduces water evaporation from the soil surface. Soil cover reduces soil crusting and subsequent surface water runoff during rainy periods.

Retention of soil moisture under cover crop mulches can be a significant advantage. Dr. Blevins and other researchers showed consistently higher soil-moisture levels for corn grown in a herbicide-killed, no-till bluegrass sod than for corn grown in conventionally plowed and disked plots (12). They concluded that the decreased evaporation and increased moisture storage under the no-till mulch allowed plots to survive a short-term drought without severe moisture stress.

Vegetation management to create a cover crop mulch

Herbicides are the most commonly used tools for cover crop suppression in conservation tillage systems. Non-chemical methods include propane flamers, mowing and mechanical tillage.

Mowing a rye cover crop when it heads out in late spring provides sufficient kill (13). The rye must be in the pollination phase, or later, to be successfully killed. When the anthers are fully extended and you can thump the stalk and pollen falls down, it is time to mow. If mowed earlier, it just grows back. Flail mowers generally produce more uniformly distributed mulch than do rotary cutters, which tend to windrow the mulch to one side of the mower. Sickle bar mowers create fairly uniform mulch, but the unchopped rye stalks can be more difficult to plant into. If late spring weather continues cool and wet, more rye regrowth will occur than if the weather remains warm and dryer. Typically, if rye is mowed at the pollination stage, regrowth is minimal and not a problem to crops grown in the mowed mulch.

In a Mississippi study, flail mowing, or rolling with rolling disk colters spaced at 4 inches, was usually as effective as herbicides in killing hairy vetch, crimson clover and subterranean clover (14). Timing is a key factor when using mowing or rolling to control cover crops. Mechanical control was most effective when the legumes were in the seed formation growth phase (mid to late April) or when stem lengths along the ground exceeded 10 inches (14). If mowing was followed with a pre-plant herbicide application of Atrazine, the legume kill was even more effective.

Researchers at Ohio State University developed a mechanical cover crop killing tool used to take out a cover crop without herbicides. They call it an undercutter because it uses wide V-blades which run just under the soil surface to cut off the cover crop from its roots. The blades are pitched to 15 degrees allowing the blades to penetrate the soil and provide a slight lifting action. Mounted on the same toolbar behind the cutter blades is a rolling basket to flatten and distribute the undercut cover crop. The undercutter was tried on several cover crops and effectively killed crimson clover, hairy vetch, rye, and barley. These undercutters could be made from locally available stock by innovative tinkerers.

Steve Groff of Cedar Meadow Farm in Lancaster County, Pennsylvania, uses a 10-foot Buffalo rolling stalk chopper from Fleischer Manufacturing (15) to transform a green cover crop into a no-till mulch (see Figure 1). Under the hitch-mounted frame, the stalk chopper has two sets of rollers running in tandem. These rollers can be adjusted for light or aggressive action and set for continuous coverage. Steve says the machine can be run up to 8 miles an hour and does a good job of killing the cover crop and pushing it right down on the soil. It can also be used to flatten down other crop residues after harvest. Groff improved his chopper by adding independent linkages and springs to each roller. This modification makes each unit more flexible to allow continuous use over uneven terrain. Following his chopper, Groff transplants vegetable seedlings into the killed mulch. He direct-seeds sweet corn and snap beans into the mulch. For more information on this system, order Steve's videos listed under the **Videos** section of this publication, or visit his Web page, which is listed under the **Web Resources** section. At the Web site you can see photos of these machines in action, and test-plot results comparing flail mowing, rolling, and herbicide-killed cover crops.

Figure 1. Steve Groff's modified rolling stalk chopper. (From www.cedarmeadowfarm.com)

Two USDA-ARS researchers, Drs. Aref Abdule-Bake and John Teasdale of the Beltsville Maryland Research Center, have developed a cover-crop roller (Figure 2) that acts, in principle, similarly to Steve Groff's rolling chopper. In their extensive research trials using hairy vetch, they no-till planted tomatoes into a mechanically killed hairy vetch cover crop (Figure 3). Details of their research—and other useful information on flail-mowing of cover crops and direct no-till seeding of sweet corn and snap beans into mechanically killed cover crops—can be seen in the USDA Farmer's Bulletin No. 2279, listed under the **Web**

Resources section below. As of this writing the bulletin is available only on-line because the first printing of it was all distributed to farmers and their advisors in a very short time.

Figure 2. A homemade roller to kill cover crops (From USDA Farmer's Bulletin No. 2279).

Planting cover crops known to readily winter-kill is another non-chemical means of vegetation management. Spring oats, buckwheat, and sorghum fill this need. They are fall-planted early enough to accumulate some top growth before freezing temperatures kill them. In some locations, oats will not be completely killed and some plants will regrow in the spring. Winter-killed cover crops provide a dead mulch through the winter months instead of green cover. They are used primarily in regions where precipitation is limited, such as West Texas, and in situations where farmers want to plant early in the spring and avoid overwintered cover crops altogether.

Limitations of cover crops

The recognized benefits of green manuring and cover cropping—soil cover, improved soil structure, nitrogen from legumes—need to be evaluated in terms of cash returns to the farm as well as the long-term value of sustained soil health. For the immediate growing season, seed and establishment costs need to be weighed against reduced nitrogen fertilizer requirements and the effect on cash crop yields.

Water consumption by green manure crops is a concern and is pronounced in areas with less than 30 inches of precipitation per year. Still, even in the fallow regions of the Great Plains and Pacific Northwest, several native and adapted legumes (such as black medic) seem to have potential for replacing cultivation or herbicides in summer fallow. There is always additional management required when cover crops of any sort are added to a rotation. Turning green manures under or suppressing cover crops requires additional time and expense, compared to having no cover crop at all.

Figure 3. Transplanting tomatoes into mechanically killed hairy vetch. (From USDA Farmer's Bulletin No. 2279).

Insect communities associated with cover crops work to the farmer's advantage in some crops and create a disadvantage in others. For example, certain living mulches enhance the biological control of insect pests of summer vegetable crops and pecan orchards by providing favorable habitats for beneficial insects. On the negative side, winter legumes that harbor catfacing insects such as the tarnished plant bug, stink bug, and plum curculio can pose problems for apple or peach orchardists in the eastern U.S. Nematodes encouraged by certain legumes on sandy soils are another concern of farmers, as are cutworms in rotations following grain or grass crops.

Cover crops in rotation

Cover crops can fit well into many different cropping systems during periods of the year when no cash crop is being grown. Even the simplest corn/soybean rotation can accommodate a rye cover crop following corn, which will scavenge residual nitrogen and provide ground cover in the fall and winter. When spring-killed as a no-till mulch, the rye provides a water-conserving mulch and suppresses early-season weeds for the following soybean crop. Hairy vetch can be planted behind soybeans to provide nitrogen for corn the following spring. Hairy vetch is *not* a good cover crop to use when small grains are included in the rotation—if the vetch ever goes to seed it can become a terrible weed in the small grain crop. In these cases, crimson clover, sweet clover, or red clover should be used, depending on location.

Many vegetable rotations can accommodate cover crops as well. Buckwheat can follow lettuce and still be tilled down in time for fall broccoli. Hairy vetch works well with tomatoes and other warm-season vegetables. The vetch can be killed by flail mowing and tomato sets planted into the mulch. For more details on the vetch-tomato system see Steve Groff's Web page, listed under **Web Resources** below. *Managing Cover Crops Profitably* has a nice section on crop rotation with cover crops, starting on page 34. For ordering information on this handbook, see the **Publications in Print** section below.

Pest management benefits of cover crops

In addition to the soil improving benefits, cover crops can also enhance many pest management programs. Ecologists tell us that stable natural systems are typically diverse, containing many different types of plants, arthropods, mammals, birds, and microorganisms. Growing cover crops adds diversity to a cropping system. In stable systems, serious pest outbreaks are rare, because natural controls exist to automatically bring populations back into balance.

Farmers and researchers in several locations have observed and documented increased beneficial insect numbers associated with cover crops. The cover crops provide pollen, nectar, and a physical location for beneficial insects to live while they search for pest insects. Conservation tillage proves a better option than tilling because it leaves more crop residue on the surface to harbor the beneficial insects. Strip tilling or no-tillage disturbs a minimum of the existing cover crop that harbors beneficial insects. Cover crops left on the surface may be living or in the process of dying. At either of these stages they protect beneficials. Once the main crop is growing, the beneficials move onto it. By having the cover crop in place early in the growing season, the population of beneficials is much higher sooner in the growing season than would be the case if only the main crop were serving as habitat for the beneficials.

Innovative farmers are paving the way by interplanting cover crops with the main crop and realizing pest management benefits as a result. Georgia cotton farmers Wayne Parramore and sons reduced their insecticide and fertilizer use by growing a lupine cover crop ahead of their spring-planted cotton (16). They started experimenting with lupines on 100 acres in 1993 and by 1995 were growing 1,100 acres of lupines. Ground preparation for cotton planting is begun about 10 days prior to planting by tilling 14-inch wide strips into the lupines. Herbicides are applied to the strips at that time and row middles remain untouched. The remaining lupines provide beneficial insect habitat and also serve as a smother crop to curtail weeds and grasses. The lupines in the row middles can be tilled in later in the season to release more legume nitrogen.

Dr. Sharad Phatak of the University of Georgia has been working with cotton growers in Georgia testing a strip cropping method using winter annual cover crops (17). Planting cotton into strip-killed crimson clover improves soil health, cuts tillage costs, and allows him to grow cotton without any insecticides and only 30 pounds of nitrogen fertilizer. Working with Phatak, farmer Benny Johnson reportedly saved at least $120/acre on his 16-acre test plot with the clover system. There were no insect problems in the test plot, while beet armyworms and whiteflies infested nearby cotton and required 8 to 12 sprays to control. Cotton intercropped with crimson clover yielded more than 3 bales per acre compared with 1.2 bales per acre in the rest of the field (17). Boll counts were 30 per plant with crimson clover and 11 without it. Phatak identified up to 15 different kinds of beneficial insects in these strip-planted plots.

Phatak finds that planting crimson clover seed at 15 pounds per acre in the fall produces around 60 pounds of nitrogen per acre by spring. By late spring, beneficial insects are active in the clover. At that time, 6- to 12-inch planting strips of clover are killed with Roundup herbicide. Fifteen to 20 days later the strips are lightly tilled and cotton is planted. The clover in the row-middles is left growing to maintain beneficial insect habitat. When the clover is past the bloom stage and less desirable as a preferred habitat, beneficials move onto the cotton. Even early-season thrips, which can be a problem following cover crops, are limited or prevented by beneficial insects in this system. Movement of the beneficials coincides with a period when cotton is most vulnerable to insect pests. Following cotton defoliation in the early fall, the beneficials hibernate in adjacent non-crop areas.

Phatak points out that switching to a whole-farm focus while reducing off-farm inputs is not simple. It requires planning, management, and several years to implement on a large scale. It is likewise important to increase and maintain organic matter, which stimulates beneficial soil microorganisms. Eventually a "living soil" will help keep harmful nematodes and soil-borne fungi under control (17).

The two *Creative Cover Cropping* videos from California, listed under the **Videos** section below, show footage of cover crop systems used to provide beneficial insect habitat and how to manage them. *Managing Cover Crops Profitably* has a section on using cover crops for pest management starting on page 25. See the **Publications in Print** section for ordering information. Additional concepts and practices associated with cover crops as a tool to build soil health and increase agroecosystem diversity in relation to pest management are contained in the following ATTRA publications: *Farmscaping to Enhance Biological Control* and *Alternative Nematode Control*.

Table 6. Optimum nitrogen rates and profitability of several cover crops (19).

Cover Crop	Corn Yield	Optimum N rate
	bu./acre	lbs N/acre
No cover crop	142	100
Winter wheat	142	126
Hairy vetch	148	79
Austrian winter peas	153	107
Crimson clover	148	94

Economics of cover crops

The most obvious direct economic benefit derived from legume cover crops is nitrogen fertilizer savings. In most cases these savings can offset cover crop establishment costs. Indirect benefits include herbicide reduction in the case of an allelopathic rye cover crop, reduction in insect and nematode control costs in some cases, protection of ground water by scavenging residual nitrate, and water conservation derived from a no-till mulch. Longer-term benefits are derived from the buildup of organic matter resulting in increased soil health. Healthy soils cycle nutrients better, don't erode, quickly absorb water after each rain, and produce healthy crops and bountiful yields.

With annual cover crops, the highest cost is seed. Hairy vetch and crimson clover typically range from 50¢ to $1.50 per pound. With a 20-pound per acre seeding rate, seed costs range from $10 to $30 per acre. With a 25-pound seeding rate at 85¢ / lb and a $6.50 no-till drilling cost, it would cost $28 to plant an acre of this cover crop.

In a Maryland study, hairy vetch was compared to a winter wheat cover crop or no cover crop at two different locations (coastal plain and piedmont) (18). Corn was grown following the cover crops. Nitrogen fertilizer was used with the cover crops at varying rates. The most profitable cover crop and nitrogen fertilizer combination used more than 100 lbs of additional nitrogen per acre plus the cover crop. At $2.50 per bushel corn price, highest returns at the coastal plain location were realized with 120 lbs of additional nitrogen per acre. Profits were as follows: $53.75 per acre from no cover crop, $95.62 from hairy vetch, and $32.47 from winter wheat cover crop. All corn crops needed additional nitrogen. Lower N rates were less profitable. At the piedmont location, also with $2.50 corn, winter fallow was most profitable at $68.03 with 40 lbs per acre additional N, hairy vetch was profitable at $56.57 with 40 lbs per acre, and winter wheat was profitable at $30.12 with 100 lbs of additional nitrogen.

In another Maryland study (19), optimum nitrogen rates for corn were determined when corn followed four cover crops, compared to a winter fallow (no cover crop) treatment. Corn was grown following each cover crop treatment at various nitrogen rates over a three-year period. The results are shown in Table 6. The optimum nitrogen rate is the rate above which no additional yield increases are realized. The researchers concluded that cover crops can benefit a succeeding corn crop not only by supplying nitrogen but also by increasing maximum yield of the system (19).

Many studies have shown that legume cover crops can replace a portion of the fertilizer nitrogen requirements for a following crop. Some of these replacement values can be seen in Table 7. The economic value of these nitrogen replacements can be calculated by using a local nitrogen price. These costs can then be compared to cover crop seed and planting costs. These simple nitrogen cost comparisons do not take into account the benefits of improved soil tilth and increased water infiltration resulting from cover crops.

In a Kentucky study (25), economic returns above direct expenses for no-till corn were $64 greater with hairy vetch plus 90 lbs of nitrogen fertilizer per acre than with no cover crop plus the same nitrogen rate. This advantage was mostly due to the yield increase under the legume cover crop of 36 bushels per acre. Some researchers have stated that advantages of legume cover crops can only be realized if they increase yields of a following crop over yields obtained from no cover crop. In other words, the nitrogen replacement value is insufficient to offset the establishment costs of the cover crop without an increase in crop yield. When these yield increases beyond the nitrogen benefit occur, they are due to improved soil water use efficiency and other soil health benefits from the cover crop.

Table 7. Nitrogen fertilizer replacement value of legume cover crops.

Cover Crop	N replacement value (lbs/acre)	Reference
Hairy vetch	80-89	Ebelhar, et al., 1984 (20)
Hairy vetch	170	Utomo, et al., 1990 (21)
Winter legumes	64-69	Hargrove, et al.,1986 (22)
Hairy vetch	110	McVay, et al., 1989 (23)
Crimson clover	88	McVay, et al., 1989 (23)
Winter legumes	75	Tyler, et al., 1987 (24)

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15) Henke Machine—Buffalo Equipment
2281 16th Avenue
P.O. Box 848
Columbus, NE 68602-0848
800-228-1405
402-564-3244

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Resources

In most states the Extension service and Agricultural Experiment Stations offer free or low-cost publications on cover crops to state residents. Examples include: *Effects of Winter Cover Crops on Yield of Cotton and Soil Properties* (Arkansas Agricultural Experiment Station Bulletin 924), *Planting Guide for Forage Crops* (North Carolina Extension Service publication AG-226), and *Cover Crops* (Mississippi Cooperative Extension Service Publication 1552). Contact these local sources to obtain information adapted to your immediate area.

Publications in Print

Managing Cover Crops Profitably, 2nd Edition. 1998. The Sustainable Agriculture Network. This publication is one of the most comprehensive hands-on resources available. The book is organized by the different geographic regions of the United States. Covered in the book are selection of the best species for your location, planning profitable crop rotations, crop yield benefits following cover crops, and fertilizer reduction realized from cover crops. Chapters on 18 different cover crop species and charts rating many factors for each species, including drought tolerance, nitrogen yield, and seeding rates. The top six high-performing cover crops for each region are discussed. This publication may be ordered for $19.00 plus $3.95 shipping from:

Sustainable Agriculture Publications
210 Hills Building
University of Vermont
Burlington, VT 05405-0082
802-656-0471

Excerpts from the 2nd Edition can also be found on the SAN Web site: http://www.sare.org/mccp2/

Northeast Cover Crop Handbook. 1994. 118 pages. Marianne Sarrantonio. Among the topics covered in this comprehensive and practical manual on using cover crops are how to choose the right cover crop for your operation, building a rotation around cover crops, choosing the best species for the whole farm, estimating the nitrogen contribution from a green manure, looking at soil improvements from cover crops, and lowering the cost of cover cropping. The book is well written and easy to read, with lots of drawings and simple charts. The appendix contains detailed management practices for 20 cover crop species, cover crop seed sources, and other information sources. To order this publication send $12.00 plus $5.50 shipping and handling to:

Rodale Institute Bookstore
611 Siegfriedale Road
Kutztown, PA 19530
800-832-6285
610-683-6009
http://www.rodaleinstitute.org

Green Manuring: Principles and Practice of Natural Soil Improvement. 1989. 51 pages. This publication contains an excellent review of the benefits and uses of green manure cover crops. This 51-page spiral-bound book is largely based on green manuring trials in Switzerland and is supplemented with cover crop data compiled by Woods End Agricultural Institute of Maine and The New Alchemy Institute of Massachusetts. Although much of the discussion is based on the use of green manures in Switzerland, the cultural practices are just as applicable to farming systems in the United States. Tables include seeding rates and cost of seed per acre, biomass yields and nutrient contents, and characteristics of selected living mulches. The 1989 edition, unlike the earlier editions, also contains an extensive list of seed sources in the U.S. It is available for $20, which includes shipping and handling, from:

Woods End Agricultural Institute
PO Box 297
Mt. Vernon, ME 04352
207-293-2457
http://www.woodsend.org

Covercrops for California Agriculture by P.R. Miller, W.L. Graves, W.A. Williams, and B.A. Madison is California Extension Leaflet No. 21471, published in December of 1989. This 24-page leaflet contains information on using cover crops for soil improvement, selecting cover crops, growing and working in cover crops, biological interactions, and an appendix on cover crop management systems. It can be obtained for $3.50 plus $2.00 shipping and handling from:

University of California, ANR
Comunication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Cover Cropping in Vineyards by Chuck Ingles, University of California Publication number 3338. Published in 1998 with 168 pages. The publication offers cover cropping methods for enhancing vineyard performance. Provides detailed information on how cover crops promote ecological stability. Useful to vineyard owners, managers, consultants, and pest control advisors. Available for $20 plus $5 shipping and handling from:

University of California, ANR
Comunication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Cover Crops: Resources for Education and Extension. 1998. 3-ring binder. To order, send $20.00 postpaid, U.S. check or money order (payable to "UC Regents"; write title of publication on the check) to:

UC SAREP
University of California
One Shields Ave.
Davis, CA 95616-8716
530-752-7556
530-754-8550 FAX
sarep@ucdavis.edu
http://www.sarep.ucdavis.edu

Videos

No-till Vegetables by Steve Groff. 1997. Steve is a 15-year no-till farmer in Lancaster County, Pennsylvania, who uses cover crops extensively in his crop fields. Steve farms 175 acres of vegetables, alfalfa, and grain crops on his Cedar Meadow Farm. This video leads you through selection of the proper cover crop mix to plant into and how to control cover crops with little or no herbicide. You will see Groff's mechanical cover-crop-kill method, which creates ideal no-till mulch without herbicides. Vegetables are planted right into this mulch using a no-till transplanter. He grows high-quality tomatoes, pumpkins, broccoli, snap beans, and sweet corn. After several years of no-till production his soils are very mellow and easy to plant into. You'll also hear comments from leading researchers in the no-till vegetable area. Order this video for $21.95 plus $3.00 shipping from:

Cedar Meadow Farm
679 Hilldale Road
Holtwood, PA 17532
717-284-5152
http://www.cedarmeadowfarm.com

Creative Cover Cropping in Annual Farming Systems. 1993. Produced by the University of California, this video depicts opportunities and constraints of cover crop use. The film shows many types of cover crops used in various annual cropping systems for soil fertility and pest management. 24 minutes. Item number V93-V.

Creative Cover Cropping in Perennial Farming Systems. 1993. Produced by the University of California. Teaches how cover crops can be used to protect and improve soil fertility, enhance pest control, and provide other benefits. Creative management options are shown with a wide variety of cover crops used in orchards and vineyards. 27 minutes. Item number V93-W.

To order either or both of these videos send $15.00 plus $4.00 shipping and handling each to:

University of California
ANR Communication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Web Resources

USDA's Sustainable Agriculture Network (SAN)
http://www.sare.org/

This site offers the first edition of Managing Cover Crops Profitably on-line and a database of other sustainable agriculture research and education projects. Many of these projects have a cover crop component and some are focused on cover crops.

Managing Cover Crops Profitably
http://www.sare.org/handbook/mccp2/index.htm

The on-line version of the first edition mentioned in the paper publication listed above. It summarizes more than 30 cover crops by region. Published in 1991.

UC SAREP Cover Crop Resource Page
http://www.sarep.ucdavis.edu/ccrop

This is the database of all databases when it comes to cover crops. The UC-SAREP Cover Crop Database includes more than 5,000 items gleaned from more than 600 separate sources, including journal articles, conference proceedings, standard textbooks, unpublished data, and personal communications from researchers and farmers. The information in the database concerns the management and effects of more than 32 species of plants usable as cover crops. More *than 400 different cover crop images are also available for online viewing. One limitation — the database is regionally geared to the Mediterranean climate of California. Ideally, each region of the U.S. should enjoy such site-specific information.*

The Farming Connection
http://sunsite.unc.edu/farming-connection/covercro/home.htm

This site has farmer features and links to other cover crop sites. It also contains seed sources, general information, Steve Groff's No-till Vegetables video listing, and the first edition of Managing Cover Crops Profitably.

Ohio State On-line Ag Facts
http://ohioline.osu.edu/agf-fact/0142.html

This site has an on-line version of Cover Crop Fundamentals by Alan Sundermeier, publication number AGF-142-99. This publication covers the benefits of cover crops, planting times, types of cover crops, managing cover crop growth, and return on investment.

Michigan Cover Crops, Michigan State University and Kellogg Biological Station
http://www.kbs.msu.edu/Extension/Covercrops/home.htm

The Basics of Green Manuring
P. Warman. EAP Publication 51, Ecological Agriculture Projects
http://eap.mcgill.ca/Publications/EAP51.htm

Cover Crops & Green Manure Crops for Vegetable Farms
Ohio Vegetable Production Guide 2000
http://www.ag.ohio-state.edu/~ohioline/b672/b672_1.html

Summer Cover Crops for Tomato Production in South Florida
http://www.imok.ufl.edu/veghort/pubs/workshop/Bryan99.htm

Cover Cropping in Potato Production
EAP Publication 71, Ecological Agriculture Projects
http://eap.mcgill.ca/Publications/EAP71.htm

Cedar Meadow Farm's New Generation Cropping Systems
http://www.cedarmeadowfarm.com

Steve Groff's New Generation Cropping Systems Web page. Shows action shots of no-till planting into mechanically killed cover crops and ordering information for Steve Groff's No-till Vegetables video mentioned above.

USDA Web Site
http://www.ars.usda.gov/is/np/tomatoes.html

1997. By Aref Abdul-Baki and John R. Teasdale. USDA Farmers' Bulletin No. 2279. 23 p. This Web site provides the USDA Farmer's Bulletin that features the no-till vegetable cropping system developed by scientists at the USDA-ARS Vegetable Laboratory in Beltsville, Maryland. This system relies on hairy vetch established in the fall, followed by a mow-down treatment the following spring to prepare a no-till bed to transplant tomatoes and other vegetable crops.

Sustainable Agriculture Network Web site
http://www.sare.org/htdocs/pubs/mccp/

Managing Cover Crops Profitably, *1st Edition (1991).*

Sustainable Agriculture Network
http://www.sare.org/htdocs/pubs/resources/index.html

Order the on-line version of: Managing Cover Crops Profitably, 2nd Edition (1998).

Multiple Impacts Cover Crops.
John Luna, Oregon State University
http://ifs.orst.edu/pubs/multiple_impacts_cover_cro.html

A comprehensive piece on cover crops and their benefits.

Cover Cropping in Row and Field Crop Systems
http://www.sarep.ucdavis.edu/ccrop//slideshows/rfshow01.htm

An online educational slide series that provides visual images and text describing the benefits and uses of cover cropping in annual crops like vegetables. 52 slides.

Cover Crop Biology: A Mini-Review
Robert L. Bugg
Sustainable Agriculture Research & Education Program, University of California
http://www.sarep.ucdavis.edu/ccrop/ccres//35.htm

Cover Crops for Sustainable Agriculture – IDRC
http://www.idrc.ca/cover_crop/index_e.html

Cover Crops and Living Mulches. Sustainable Practices for Vegetable Production in the South
Dr. Mary Peet, NCSU
http://www.cals.ncsu.edu/sustainable/peet/cover/c02cover.html

Planting Dates, Rates, and Methods of Field and Forage Crops. University of Florida, Institute of Food and Agricultural Sciences
http://edis.ifas.ufl.edu/AA127

Uses of Cover Crops by Janet Wallace, NSOGA
http://www.gks.com/nccrp/usesofcc.php3

Organic Matter/Cover Crops: Green Manure Crops for Vegetable Farms. Obtaining Acceptable Stands of Clover and Green Manure Crops. 2000 Ohio Vegetable Production Guide, Bulletin 672-00.
http://ohioline.osu.edu/b672/organic_matter_cover_crops.html

Additional Information from ATTRA

ATTRA can provide more information on specific cover crops via reprints, summaries of research, and other resources. This includes materials on living mulches, summer green manures, winter cover crops, and allelopathic cover crops, as well as on specific cover crops like hairy vetch and subterranean clover, and on the more obscure cover crops such as crotalaria, velvet bean, sesbania, and phacelia.

By Preston Sullivan
NCAT Agriculture Specialist

Edited by Paul Williams
Formatted by Gail Hardy

July 2003

The electronic version of **Overview of Cover Crops and Green Manures** is located at:
HTML
http://www.attra.ncat.org/attra-pub/covercrop.html
PDF
http://www.attra.ncat.org/attra-pub/PDF/covercrop.pdf

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Table 1.10-4.

Table 1.10-4. Seeding rate and aboveground biomass production of cover crops broadcast into standing soybean crop at time of first leaf drop (Lancaster County, 1999-2001).

Cover crop	Seeding rate (lbs/A)	Dry matter production (T/A)	Soybean yield (Bu/A)
Rye	156	2.0	44.8
Ryegrass	30	0.9	39.4
Summer Oats	156	0.2	39.7
Winter wheat	160	1.4	45.4
Rape*	12	0.3	41.4
No cover crop			37.3

*Rape data for 2000 and 2001 only. Data from the Penn State Southeast Research and Extension Center, Landisville.

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Table 1.10-6. Characteristics of common cover crops.

Species	Life cycle[1]	Hardy through zone	Seeding rate[2] (lb/A)	Seeding depth (inches)	Seeding date	N-capture/ fertilizer equivalency (lbs/A)	Advantages	Disadvantages
Grasses (Cool season)								
Cereal rye (*Secale cereale* L.)	WA	3	112 (2 bu)	1–2	Sept.–Nov. 1	Excellent nutrient scavenger (esp. N)	Most cold tolerant of commonly used cover crops; providing living cover in winter and spring, erosion control, weed suppression, nutrient recycling, organic matter improvement, soil tilth improvement; earliest small grain to mature	Regrowth may occur if not completely controlled; explosive growth in spring poses termination challenges; possible following crop suppression due to allelopathy or nutrient tie-up; may attract some insect pests.
Winter wheat (*Triticum aestivum* L.)	WA	4	120 (2 bu)	1–2	Sept.–Nov. 1	Excellent nutrient scavenger (esp. N)	Cold tolerant in most of PA; rapid growth; common varieties not as tall as rye and therefore easier to manage; provides living cover in winter and spring, erosion control, weed suppression, nutrient recycling, organic matter improvement, soil tilth improvement	Accumulates lower amounts of biomass than rye; possible following crop suppression due to nutrient tie-up; may attract some insect pests; matures after triticale
Winter triticale	WA	3	120 (2 bu)	1–2	Sept.–Nov. 1	Excellent nutrient scavenger (esp. N)	Intermediate between wheat and rye	Intermediate between wheat and rye; matures after barley
Winter barley (*Hordeum vulgare* L.)	WA	6	120 (2.5 bu)	1–2	Sept.–Oct. 15	Good nutrient scavenger	Cold tolerant in southern parts of PA; common varieties not as tall as rye and therefore easier to manage in spring; provides living cover in winter and spring, erosion control,	Winterkill is possible; accumulates lower amounts of biomass than wheat; possible crop suppression due to nutrient tie-up; matures after cereal rye

[1] A=annual; WA=winter annual; B=biennial; SLP=short-lived perennial; LLP=long-lived perennial; NFT= no frost tolerance
[2] Higher rates may be necessary for broadcast seedings

Species	**Life cycle[1]**	**Hardy through zone**	**Seeding rate[2] (lb/A)**	**Seeding depth (inches)**	**Seeding date**	**N-capture/ fertilizer equivalency (lbs/A)**	**Advantages**	**Disadvantages**
Grasses (Cool season)								
							weed suppression, nutrient recycling, organic matter improvement, soil tilth improvement	
Spring oats (*Avena sativa* L.)	SA	8	100 (3 bu)	1–2	Aug.–Sept. 15	Average nutrient scavenger	Very easy to manage because winterkills; provides erosion control, weed suppression, nutrient recycling, organic matter improvement, soil tilth improvement in fall, rapid growth in cool weather; ideal for quick fall cover or nurse crop with legumes; may produce more biomass in fall than other winter small grains if planted early	Winterkills in most of PA, no living root system in winter and spring; erosion control may be limited in spring; high lodging potential; susceptible to disease and insect pests
Annual ryegrass (*Lolium* spp.)	WA	6	20	0.25–0.5	Aug.–Sept. 15	Good nutrient scavenger	Cold tolerant in southern parts of PA; varieties not as tall as rye; provides living cover in winter and spring, erosion control, weed suppression, nutrient recycling, organic matter improvement, soil tilth improvement, high-quality fodder	May winterkill; may be difficult to control; low heat tolerance; may harbor insects; may reseed and become weed
Legumes								
Hairy vetch (*Vicia villosa Roth*)	WA	4	15–20	1–2	Aug.–early Sept.	80–160	Most cold tolerant and high biomass production; above-average drought tolerance; adapted to wide range of soil types; combines well with small grains	Requires early fall establishment; slow to establish; matures in late spring; high P and K requirement for maximum growth; can harbor pests; potential weed problem in winter grain; glyphosate not full-proof for control
Crimson clover (*Trifolium incarnatum* L.)	WA/SA	6	15–20	0.25–0.5	Aug.–early Sept.	70–130	Fairly cold tolerant; rapid fall growth; high biomass production; matures midspring; above-average shade tolerance; forage	May winterkill; requires early fall establishment; poor heat and drought tolerance; residue has tough stems, difficult to no-till plant into

[1]A=annual; WA=winter annual; B=biennial; SLP=short-lived perennial; LLP=long-lived perennial; NFT= no frost tolerance
[2]Higher rates may be necessary for broadcast seedings

Species	Life cycle[1]	Hardy through zone	Seeding rate[2] (lb/A)	Seeding depth (inches)	Seeding date	N-capture/ fertilizer equivalency (lbs/A)	Advantages	Disadvantages
Grasses (Cool season)								
							use (no bloat); good nematode resistance	
Red clover (*Trifolium pratense* L.)	SLP (2–3 yrs)	4	8–10	0.25–0.5	Feb.–June	70–120	Survives winter; deep taproot; soils; tolerates wet soil conditions and shade; forage use, especially if mixed with grass	Needs to be established before midsummer because initial growth slow; high P and K requirements for maximum growth; hard seed can persist creating volunteer problems; pure stand forage causes bloat; vulnerable to some pathogens, insects
Field peas (*Pisum* spp.) (e.g. Austrian winter pea)	SA/WA	7	50–80	1.5–2.0	Aug.–Sept. 15	50–150	Rapid growth in cool weather; versatile legume; interseed with cereal and *Brassica* spp.; used as food or feed	May winterkill; shallow root system; sensitive to heat and humidity; susceptible to diseases, insect pests
Other Crops								
Buckwheat (*Fagopyrum esculentum* Moench)	SA	NFT	35–134	0.5–1.5	Spring or late summer	Fair to good nutrient scavenger (esp. P, Ca)	Grows on wide variety of soils (infertile, poorly tilled, low pH); rapid growth; quick smother crop and good soil conditioner	Limited growing season; not winter hardy; limited biomass accumulation; frost sensitive; poor growth on heavy limestone soils; occasional pests
Brassicas (*Cruciferae* family) (e.g. rape, radish)	WA	8	5–12	0.25–0.5	Spring or fall	Good nutrient scavenger (esp. N, P, Ca)	Quick establishment in cool weather; prevent erosion in fall (radish) and spring (canola, rape); radish easy to manage because winterkills; deep, thick root systems; compaction alleviation; nutrient cycling; weed suppression	Radish winterkills in all of PA, while canola/rapeseed may winterkill in northern parts of PA; radish leaves soil bare in spring, therefore mix with a small grain

[1]A=annual; WA=winter annual; B=biennial; SLP=short-lived perennial; LLP=long-lived perennial; NFT= no frost tolerance
[2]Higher rates may be necessary for broadcast seedings

DISADVANTAGES OF COVER CROPS

While cover crops have many potential benefits, they also have a few disadvantages that may be minimized by careful management.

- Additional expenses: These include cover crop seeds, labor and equipment costs for planting, and any alternative equipment required because of greater amounts of residue.
- Competition with cash crops: Unmanaged or incompletely managed cover crops can behave like weeds, competing with cash crops for water, light, and nutrients. In dry years, cover crops may leave less water in the soil for cash crops.
- Pests: Just as cover crops may harbor beneficial organisms, they may also harbor pests. This may be reduced by selecting cover crops that don't provide a "green bridge" for pests of the following (or nearby) cash crop. For example, clover root curculio is a common pest of red clover that can also attack alfalfa.

RESOURCES FOR MORE INFORMATION

Clark, A. *Managing Cover Crops Profitably.* 3rd ed. Beltsville, Md.: Sustainable Agriculture Network, 2007. www.sare.org.

Curran, W. S., et al. *Cover Crops for Conservation Tillage Systems.* Conservation Tillage Series 5. University Park: The Pennsylvania State University, 2006. pubs.cas.psu.edu/FreePubs/pdfs/uc128.pdf.

Penn State Agronomy Guide, 2009–2010. University Park: The Pennsylvania State University, 2009. agguide.agronomy.psu.edu.

Prepared by Eric Nord and Rich Smith, postdoctoral research associates in crop and soil sciences; Bill Curran, professor of weed science; and Matt Ryan, Ph.D. candidate in ecology.

Photographs by Bill Curran, Nelson Debarros, Dave Mortensen, Matt Ryan, and Charlie White

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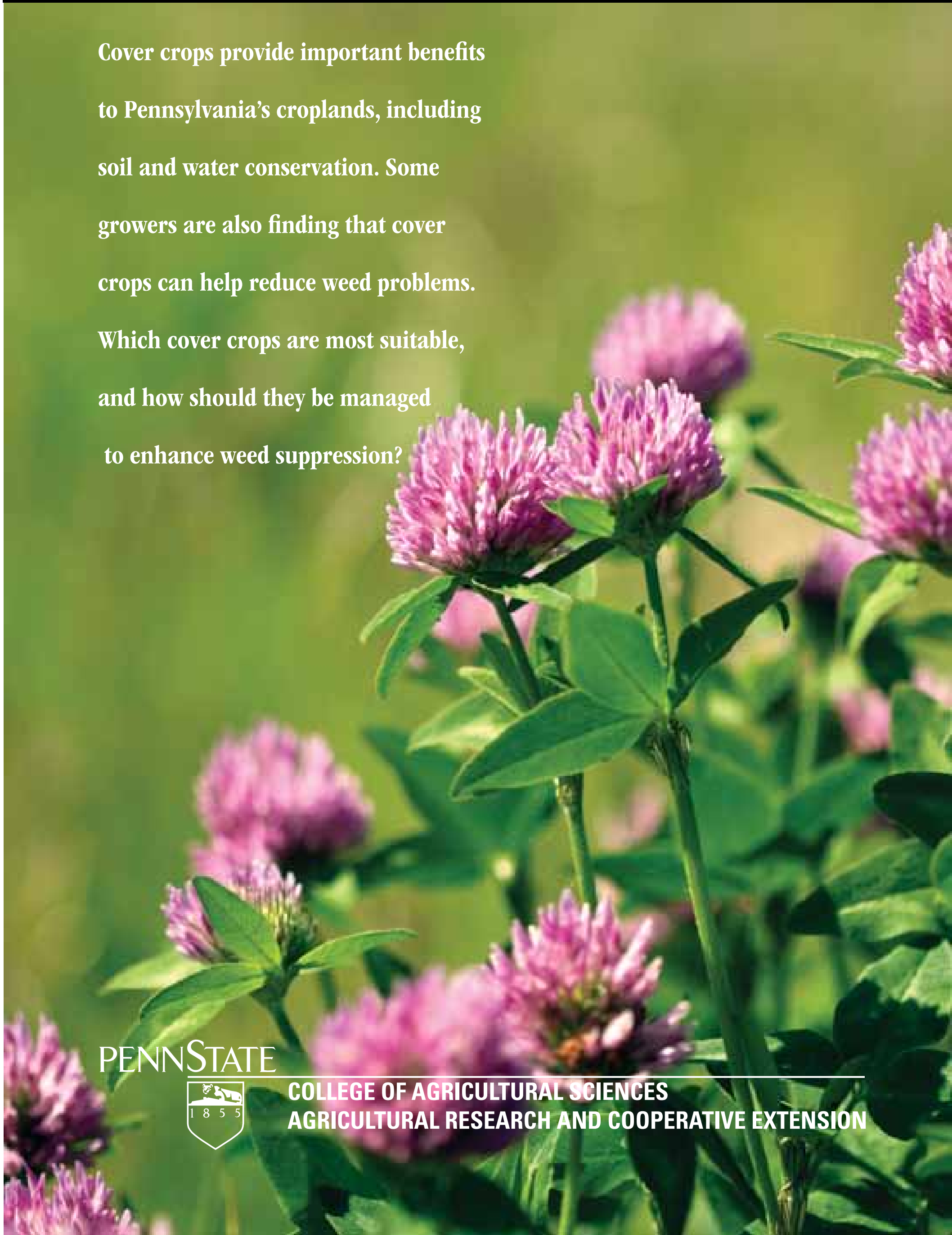
AGROECOLOGY IN PRACTICE

Suppressing Weeds Using Cover Crops in Pennsylvania



Cover crops provide important benefits to Pennsylvania's croplands, including soil and water conservation. Some growers are also finding that cover crops can help reduce weed problems. Which cover crops are most suitable, and how should they be managed to enhance weed suppression?

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TYPES OF COVER CROPS

The life history of a plant species affects how it may be used as a cover crop. Summer or winter annuals, biennials, and perennials can be used for cover crops where needed. The choice of cover crop species will depend on management goals. Winter annual cover crops can generally fit into a crop rotation without requiring that land be fallowed.

Legume cover crops provide an important source of nitrogen and can replace or reduce the need for nitrogen fertilizer. This is of particular importance preceding nonlegume crops. Grass cover crops are particularly beneficial in erosion reduction because they have a fibrous root system and can produce many stems.

In some cases, cover crop mixtures may be better than individual cover crops. For example, oats may be used as a nurse crop for hairy vetch planted in early fall. The oats grow more quickly in the fall, providing partial soil coverage and nutrient-trapping benefits before they are winter-killed, which prevents competition with the hairy vetch in the spring.

ESTABLISHMENT OF COVER CROPS

Cover crop planting should take into account the fertility of the soil. A soil test is a good way to begin. Pest history should also be considered, as should the history of herbicide application.

Cover crops can be established by conventional, no-till, or broadcast seedings, though broadcast seeding is generally less successful. Frost seeding may be effective for the establishment of cover crops in early spring. Aerial seeding can allow a cover crop to be established before the cash crop is harvested.

MANAGING COVER CROPS TO HELP SUPPRESS WEEDS

- **Species selection:** Choose cover crops based on your objectives. If weed suppression is an objective, select an aggressive species that will cover the ground quickly. If you desire a cover crop that will protect the soil through the fall and winter and suppress winter annual weeds, plant a winter cereal in late summer or early fall. See the cover crop species information table and the accompanying phenology chart to determine which cover crops may be suitable to meet your objectives.
- **Establishment date:** Establishing a hardy winter cover, such as cereal rye, as early in the fall as possible will result in greater cover crop biomass over the winter and rapid growth during the spring. Other establishment dates may be preferable for different cover crops depending on the species and your objectives.
- **Seeding rate, row spacing, and planting arrangement:** The seeding rate and arrangement of the cover crop can influence weed suppression. Planting at higher-than-normal seeding rates and in narrow rows can influence the amount of soil cover, particularly in the first several weeks after seeding. Thick, dense cover crop stands can help reduce the establishment of weeds.
- **Soil fertility:** It is important to provide adequate soil fertility to cover crops to ensure they are competitive and successful. This is particularly true for small grains like cereal rye and wheat, which require adequate nitrogen. Lime may be necessary to maintain or raise the soil pH for legumes like hairy vetch and red clover. Regular soil tests will help you determine how best to manage your cover crops so as to maximize their beneficial effects on weed suppression and soil quality.
- **Termination timing:** Allowing a cover crop to grow as long as possible before controlling it reduces weed populations through competition for light, nutrients, and moisture. In no-till, letting the cover crop achieve maximum dry matter production (often at flowering or beyond) will increase weed suppression. This may mean delaying termination and cash crop planting until the cover crop has achieved sufficient growth to suppress weeds (weed suppression may require dry matter production of 4,000 pounds per acre or more). Keep in mind, however, that high-biomass cover crops can be more challenging to manage, may need shorter-season cash crops to allow for adequate cover crop growth, and may require specialized planting equipment or may increase the potential for some insect pest problems.

CONTROL OF COVER CROPS

Control of a cover crop is important to avoid interference with cash crops.

- Tillage controls cover crops and incorporates cover crop residues into the soil. This speeds up degradation and the release of nutrients for the primary crop but does not create a weed-suppressive mulch layer. Tillage targeted for a certain time period to interfere with emergence of a problem weed may be useful in addition to cover crops.
- Mowing can be an effective control if it occurs after flowering, but some cover crops can regrow after mowing.
- Rolling with a roller/crimper can effectively control some cover crops, especially when rolling occurs after the cover crop has begun to flower. Rolling creates a longer-lived mulch layer than mowing.
- Herbicides can also be effective controls of cover crops, but product selection and application timing are important. In general, allow at least one week between application and primary crop planting to allow complete cover crop kill.

OTHER BENEFITS OF COVER CROPS

Cover crops can be a useful tool for suppressing weeds in cash crops, but they also have many other benefits.

- **Erosion control:** Soil that is covered is less prone to erosion for at least three reasons. First, living leaves and plant residues soften the impact of raindrops, reducing the amount of soil they dislodge. Second, plant stems and residues reduce the speed of water flowing over the soil surface. Third, roots hold the soil particles, preventing them from washing away.
- **Organic matter and soil tilth:** Soil organic matter is important in promoting good soil structure, which increases drainage and aeration. Organic matter is also important for cation exchange (nutrient-holding) capacity. Cover crops can be a great source of organic matter and can help maintain (or gradually increase) soil organic matter.
- **Nitrogen fixation:** Legume cover crops, through their association with certain soil bacteria, are able to fix nitrogen from the atmosphere. This nitrogen is slowly released for cash crops when the cover crop residues decay.
- **Nutrient trapping or scavenging:** Cover crops that are actively growing during seasons when the soil would otherwise be bare can trap nutrients that might otherwise be lost, either through leaching or runoff, which can affect water quality.
- **Beneficial organisms:** Cover crops may improve the soil environment for organisms that improve soil quality or prey on pests.
- **Feed and forage:** Some cover crops, especially grasses, can be used for livestock feed, either by grazing or mechanical harvest.

(continued on back panel)

WEED-SUPPRESSIVE COVER CROPS FOR PENNSYLVANIA

A large number of plant species can be effectively used as cover crops. The table below focuses on several common species that are useful for weed suppression across most of Pennsylvania. See the "Resources" section for more information.

Table 1. Selected cover crops.

Species, Life Cycle	Seeding Rate (lb/A)	Seed Cost ($/A)	Advantages	Disadvantages
Hairy vetch *Vicia villosa*, winter annual	20–40	$30.00–100.00	▪ Fixes 60–250 lb/A (avg.110) of N ▪ Cold tolerant and high yielding ▪ Relatively drought tolerant ▪ Adapted to wide range of soil types	▪ Slow establishment in early fall; little winter cover ▪ Late maturation in spring ▪ High P and K requirement for max. growth ▪ Potentially weedy in small grains ▪ Winter hardiness and maturity of cultivars can differ
Red clover *Trifolium pratense*, short-lived perennial	7–18	$7.00–27.00	▪ Fixes 100–110 lb/A of N ▪ Deep taproot ▪ Adapted to wet soils, humid areas, and shade ▪ Flexible; can be used as a forage (usually mixed with grass)	▪ Slow initial growth, high P and K requirement for max. growth ▪ Pure-stand forage use causes bloat ▪ Vulnerable to several pathogens and insects
Cereal rye *Secale cereale*, winter annual	60–200	$7.00–38.00	▪ Excellent scavenger of nutrients, esp. N ▪ Cold tolerant, late seeding possible, fast fall growth ▪ Rapid growth aids weed suppression ▪ Flexible; can be harvested for grain	▪ Regrowth may occur if control is incomplete; difficult to manage when mature ▪ Possible crop suppression caused by allelopathy or nutrient immobilization ▪ Potentially weedy in small grains ▪ May harbor small grain insects and diseases
Winter wheat *Triticum aestivum*, winter annual	120	$12.00–24.00	▪ Excellent scavenger of nutrients, esp. N ▪ Cold tolerant, late seeding possible, fast fall growth ▪ Flowers later than rye and can be harvested for grain ▪ Rapid growth aids weed suppression	▪ Produces less biomass than rye; possible crop suppression caused by nutrient immobilization ▪ May harbor small grain insects and diseases
Oats *Avena sativa*, summer annual	100	$6.50–8.50	▪ Excellent scavenger of nutrients, esp. N ▪ Rapid growth in cool weather, ideal for quick fall cover ▪ Winter-kills, can be used as nurse crop for legumes	▪ May be susceptible to disease and insect pests ▪ Minimal spring residue
Forage radish *Raphanus sativa*, annual	12–14	$24.00–35.00	▪ Good nutrient scavenger, esp. N, P, Ca ▪ Quick establishment and growth aids in weed suppression ▪ Tolerates light frost, but winter-kills ▪ Deep, thick roots, drought tolerant ▪ Flexible; can be used as a forage	▪ Low tolerance for wet soils ▪ As forage, potential bloat problems (use > 25% grass) ▪ Occasional pests (flea beetle) ▪ Minimal spring residue

MANAGING COVER CROPS: TERMINATION

Cover crops can be terminated mechanically or with herbicides. Each method has advantages and disadvantages.

Mowing can be effective, but the mulch may degrade quite rapidly because it has been chopped.

Plowing can be an effective physical control for cover crops, but the benefit of a weed-suppressive surface mulch in the subsequent cash crop is lost.

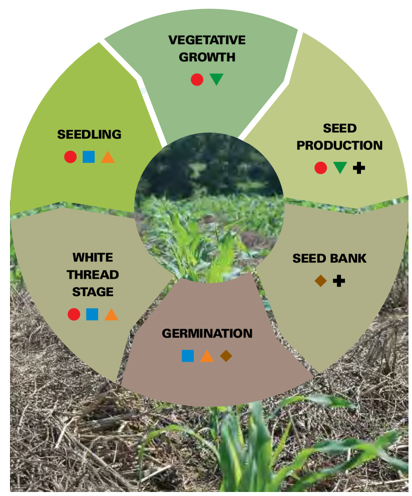
The roller/crimper offers effective physical control of some annual cover crops. It is most effective on winter annuals once they begin flowering, somewhat less effective on legumes, and not effective on perennials. The roller can produce a uniform surface mulch that decays slowly.

HOW DO COVER CROPS SUPPRESS WEEDS?

Cover crops can suppress weeds in multiple ways that affect specific stages of a weed's life cycle. The importance of each impact depends on the cover crop and the primary crop.

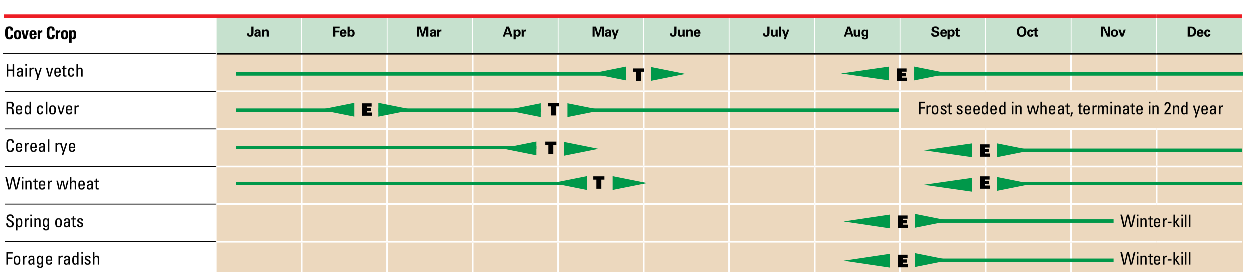
- ◆ **Micro-environment**
  Soil moisture
  Soil temperature
- ✚ **Natural enemies**
  Seed predators
  Pathogens
- ▲ **Physical supression**
  Mulch
- ■ **Allelopathy**
  Chemical inhibition
- ● **Competition**
  Space
  Nutrients
  Light
- ▼ **Control**
  Mowing
  Herbicide
  Tillage

LIFE CYCLE OF AN ANNUAL WEED



Cover Crop Phenology

Making the most of cover crops requires considering the best times for establishing and terminating a cover crop, and deciding which cover and cash crops will complement each other on your farm. This chart presents the approximate windows for establishing (E) and terminating (T) several cover crops in Pennsylvania.




Hairy vetch


Red clover


Cereal rye


Winter wheat


Oats


Forage radish

Cover Crop Rollers for Northeastern Grain Production

W. Curran and M. Ryan, Penn State University and S. Mirsky, USDA-ARS

Background

Cover crop rollers have been used for decades in Brazil, Argentina, and Paraguay to successfully manage cover crops and their residues (Derpsch et al. 1991; Ashford and Reeves, 2003). Farmers adopted these tools to manage large amounts of cover crop residue for more successful cash crop establishment in no-till systems. This "high-residue conservation tillage" system involves producing large amounts of cover crop residue and using it to suppress weeds, protect the soil from erosion, and conserve soil moisture. In the last several years, farmers in the northeast and other regions of the US have shown interest in using cover crop rollers for high residue conservation tillage. Much of the interest in the Northeast comes from organic grain and vegetable farmers who would like to reduce frequency or intensity of tillage in their rotation.

Description and potential use

Cover crop rollers have come in various designs, but are generally made from a hollow steel drum or cylinder 1 to 2 ft in diameter. The roller/crimpers used today generally have blunt blades or knives arranged on the cylinder that crimp or crush the stems of the living cover crop, which then kills it. Rollers flatten and crimp susceptible cover crops leaving an intact mat of soil protective mulch oriented in the direction of planting. This unidirectional mulch can help facilitate planting and improve seed to soil contract and ultimately cash crop emergence. In contrast to mowing the cover crop, there is less risk of cover crop regrowth when it is rolled, the intact residue decomposes slower, and weed suppression is better from the uniform surface residue.

Several designs have been tested (long-straight blades vs. curved blades vs. other designs) for cover crop control and vibration reduction (Kornecki et al. 2006; Raper et al. 2004). A common design used today has metal blades welded onto a cylinder in a chevron pattern that allows for smooth operation (Ashford and Reeves, 2003). This design was further refined by The Rodale Institute (www.rodaleinstitute.org/no-till_revolution) and is now manufactured and sold by I & J Manufacturing of Gap, PA (http://www.croproller.com/).

The Rodale style roller in action with Jeff Moyer and Dave Wilson (at The Rodale Institute) and a commercial roller in tandem with seeding soybeans on the eastern shore of Maryland. (upper photo courtesy of M. Ryan and lower photo W. Curran)

Cover crop rollers vary in width but are generally between 5 and 30 feet wide weighing at least 1000 lbs or more. Larger units are used by some farmers that employ several cylinders linked together to cover large areas more quickly. Many designs allow more weight by filling the metal drum with water. The energy required to operate a roller/crimper is similar to that required for a cultipacker and tenfold less than the energy required for mowing (Anonymous 2002). The rolled cover crop system can save organic soybean farmers up to 5-gallons of fuel per acre by reducing tillage operations (Mutch 2004) and when averaged over a three year corn-soybean-wheat rotation, no-till planting with a roller uses 25% less energy than traditional organic management (Ryan et al. 2009).

Where they work

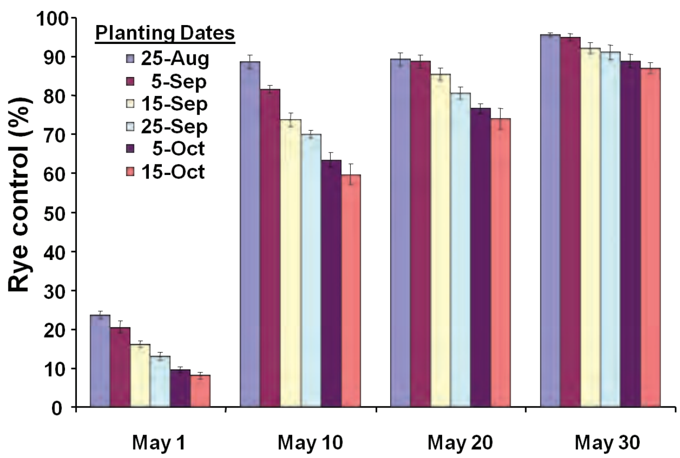
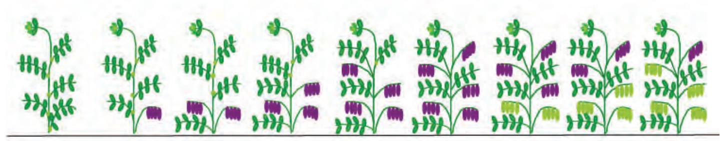


Figure 1. Percent control of cereal rye 6 weeks after rolling as influenced by planting date (Aug. 25-Oct. 15) and termination date (May 1-May 30). Bars represent standard error of the means. By the May 30 termination, fall planting date was not important—all dates were effectively controlled. Experiment was conducted in conducted in Central Pennsylvania in 2005 and 2006 (Mirsky et al. 2009).

Cover crop rollers can be effective for terminating annual crops including cereal grains; rye, wheat, oats, and barley as well as annual legumes and other forbs. Most of the research with roller/crimpers has been with cereal grain cover crops, although legume cover crops such as hairy vetch, winter pea, and crimson clover have also been evaluated (Wilson 2007, unpublished). Previous work showed that control of cereal cover crops improves with increasing plant maturity (Ashford and Reeves, 2004). The cereal grain generally needs to be well into flowering in order for the roller-crimper to provide acceptable control alone. Mirsky et al. (2009) reported that cereal rye was consistently controlled at Zadoks growth stage 61, when the anthers were clearly visible and shedding pollen. Rolling prior to this growth stage did not consistently prevent the rye cover crop from competing with the cash crop and producing viable seed. Cereal rye maturity and thus the time one must wait until it reaches the susceptible growth stage for control will depend on several factors including the fall seeding date and the temperature in the fall and spring (Figure 1). These dates will vary somewhat by year and can be delayed in the spring as we move north geographically.

Hairy vetch is another common cover crop that can be successfully terminated with a roller crimper. Research by Mischler et al. 2009 reported that consistent hairy vetch control was achieved when small pods were visible (early pod set) on the upper nodes of the plant counting down from the top (Figure 2). Although acceptable control was sometimes achieved prior to this growth stage, some regrowth occurred at some locations. Incomplete control of vetch increases the risk for vetch seed production, which can be a serious problem in subsequent winter annual crops such as wheat. The roller crimper can also work well on mixtures of cereals and legumes such as hairy vetch seeded with rye, wheat, or triticale. The timing of the operation should be based on the latest maturing species or multiple passes with a roller may be necessary. A number of cover crops are not controlled by the roller crimper including biennial or perennial legumes (alfalfa, red clover, etc.), canola, and annual ryegrass to name just a few. More cover crop species need to be tested for their suitability for using a roller-crimper.



Vegetative 1	20% Flower 2	40% Flower 3	60% Flower 4	80% Flower 5	100% Flower 6	Early Pod 7	Mid Pod 8	Late Pod 9

Figure 2. Hairy vetch growth stages based on the upper five nodes of the vine. Growth stage depends on the number of buds that have begun to bloom or produce pods. Vegetative (1), no flower buds are visible; early pod set (7), when 1-2 pods are visible; and late pod set (9) when 4+ pods are visible. Consistent control with the roller-crimper was achieved at early pod set (7).

Combinations with herbicides

Although much of the interest in the roller-crimper in North America comes from organic farmers that do not use herbicides, there is some potential to combine herbicides with the roller and use an integrated approach. This has been the basis for their use in South America where burndown herbicides are generally used. Some research has shown that the roller-crimper in combination with a burndown herbicide like glyphosate can increase the effectiveness of cover crop control. In a study by Ashford and Reeves 2003, the roller in combination with a half rate of herbicide equaled the effectiveness of the herbicide alone at the full rate. In research by Curran et al. 2007, reduced rates of glyphosate in combination with the roller desiccated cereal rye more quickly than the herbicide alone. Several weeks after application, rye control was similar between rolled and unrolled treatments that included glyphosate. Although not tested in the previous study, the rolled cover crop mat potentially provides greater weed suppression than a more upright unrolled cover due to reductions in weed emergence and reduced competition. Finally, the combination of a burndown herbicide plus the roller alleviates the need to "wait" until the cover crop is susceptible to control by the roller alone and can provide an earlier window for cash crop establishment. Small grain cover crops should be in the late boot stage or in early heading to benefit from rolling. Rolling prior to this does not generally provide sufficient cover crop biomass nor the quality (higher fiber content) necessary to suppress weeds or persist long enough to impact weed emergence. In some soybean research by Mischler et al. 2010, a sprayed and rolled rye cover crop at the late boot stage or beyond provided weed control results similar to a postemergence glyphosate and no cover in 2 of 4 study locations.

Need for good no-till equipment

High-residue conservation tillage requires planting equipment that is capable of slicing through the rolled cover crop residue, accurately placing seeds in the soil, and then covering the seed with soil. In vegetable transplant systems, similar results with seedlings are desired. Although the no-till industry has made great strides in the past 15 years toward developing planters and drills that can handle large amounts of plant residue, there continues to be challenges when establishing cash crops in large amounts of residue. Too wet or too dry soil conditions, lodged cereal cover crops at the time of rolling, and extreme amounts (greater than 10,000 lb DM/acre) of cover crop biomass can make direct seeding particularly challenging. We have been more successful using no-till planters than no-till drills where depth of seed placement can be more problematic. **Be sure to test, adjust, and refine your planting equipment prior to adopting high-residue no-till management.** Establishment of the cash crop is critical to success for this no-till system.

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[1]Professor Weed Science, PhD Candidate, and Research Ecologist.

March 30, 2010

Synthetic Mulches

Comparison of Black, White, and Silver Plastic Mulch for Pepper Production in New Jersey (American Society of Plasticulture [ASP])

Plastic Mulches (ASP)

Summary and Recommendations for the Use of Mulch Color in Vegetable Production (ASP)

How Scientists are “Tricking” Plants- Colored Mulch Research (Penn State)

The Use of Different Colored Mulches for Yield and Earliness (UCONN IPM)

Weed Management in Vegetables (WVU)

ASP Proceedings - Abstracts

Comparison of Black, White and Silver Plastic Mulch for Pepper Production in New Jersey

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Abstract: Transplanted bell peppers (*Capsicum annuum* var. 'Wizzard') were planted on May 18, 1999 at the Rutgers Agricultural Research and Extension Center in Bridgeton, New Jersey. All plots contained Kennco high raised beds and drip irrigation. The treatments consisted of six different plastic mulches and a bare ground control. The treatments were as follows: 36" silver strip on white (SW); a rippled reflective silver from Parker Foils, Inc. (S1); a flat reflective silver from Clarke Ag. Plastics (S2); black from Reddick Fumigants (BP); dull silver on brown from DeWitt Company (SB); white on white (WW); and bare ground (BG). Early yields from the first harvest , taken on July 28, 1999, were evaluated along with total yields at the conclusion of the growing season. The early yields after the first harvest from highest to lowest were: S1= 440 boxes per acre (b/a), S2= 403 b/a, SB= 370 b/a, SW= 337 b/a, WW= 314 b/a, BP= 264 b/a, and BG= 248 b/a. Total yields at the conclusion of the study from highest to lowest were: S2= 707 b/a, WW= 682 b/a, S1= 662 b/a, SB= 655 b/a, BP= 564 b/a, SW= 543 b/a, BG= 523 b/a. High temperatures after the first harvest caused a great deal of flower bud abortion and reduced late season yields. The reader should not consider the endorsement or recommendation of one brand of plastic mulch over another or one company over another, based on these study results.

There is no full paper associated with this abstract.

From American Society of Plasticulture
http://plasticulture.psu.edu

Plastic Mulches

One important component of plasticulture is plastic mulches that have been used commercially for the production of vegetables since the early 1960's, and their usage is still increasing throughout the world. Plastic mulches provide many positive advantages for the user, such as increased yields, earlier maturing crops, crops of higher quality, enhanced insect management, and weed control. They also allow other components, such as drip irrigation, to achieve maximum efficiency. Although a variety of vegetables can be grown successfully using plastic mulches, muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons, and okra have shown the most significant responses. The production of strawberries and cut flowers, like vegetables is greatly improved by the use of plasticulture. The selection of which mulch type to use will depend on factors such as the crop to be grown, season of the year, whether double or triple cropping is contemplated, and if insect management is desired.

Much of the early work on the use of plastic mulches for vegetable production was to define the impact that differently colored mulches had on soil and air temperatures, moisture retention, and vegetable yields. Based on this work three main colors of black, clear, and white predominate commercial vegetable production today, although white has been replaced largely by a co-extruded white-on-black.

Plastic mulches directly impact the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss. The color of a mulch largely determines its energy-radiating behavior and its influence on the microclimate around a vegetable plant. Color affects the surface temperature of the mulch and the underlying soil temperature. Another important factor is the degree of contact between the mulch and soil or by not being taut, often quantified as a thermal contact resistance, will greatly influence the performance of a mulch. If an air space is created between the plastic mulch and the soil by a rough soil surface, soil warming can be less effective than would be expected from a particular mulch.

The soil temperature under a plastic mulch depends on the thermal properties (reflectivity, absorbitivity, or transmittancy) of a particular material in relation to incoming solar radiation. Black plastic mulch, the predominate color used in vegetable production is an opaque blackbody absorber and radiator. Black mulch absorbs most ultra-violet

(UV), visible, and infrared wavelengths (IR) of incoming solar radiation and re-radiates absorbed energy in the form of thermal radiation or long-wavelength infrared radiation.

Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch increases soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Because thermal conductivity of the soil is high relative to that of air, much of the energy absorbed by black plastic can be transferred to the soil by conduction if contact is good between the plastic mulch and the soil surface. Soil temperatures under black plastic mulch during the daytime are generally 5° F higher at a 2-inch depth and 3° F higher at a 4-inch depth compared to those that of bare soil.

In contrast, clear plastic mulch absorbs little solar radiation but transmits 85% to 95%, with relative transmission depending on the thickness and degree of opacity of the polyethylene. The under surface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation, so much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus, daytime soil temperatures under clear plastic mulch are generally 8 to 14° F higher at a 2-inch depth and 6 to 9° F higher at a 4-inch depth compared to those of bare soil. Clear plastic mulches generally are used in the cooler regions of the United States, such as the New England states. Using clear plastic mulch will require the use of a herbicide, soil fumigant, or solarization to control weeds.

White, coextruded white-on-black or silver reflecting mulches can result in a slight decrease in soil temperature -2° F at 1-inch depth or -0.7° F at a 4-inch depth compared to bare soil, because they reflect back into the plant canopy most of the incoming solar radiation. These mulches can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial. Depending on the degree of opacity of the white mulch, it may require the use of a fumigant or herbicide because of the potential weed growth.

Another family of mulches includes the wave-length-selective or photoselective mulches, which selectively transmit radiation in some regions of the electromagnetic spectrum but not in the photosynthetic region. These mulches absorb protosynthetically active radiation (PAR) and transmit solar infrared radiation (IR), providing a compromise bFriday, April 4, 2008 4:07 PMord the weed control properties of black mulch but are intermediate between black and clear mulch in terms of increasing soil temperature. The color of these mulches can be blue-green (IRT-76, AEP Industries Inc., Moonachie, N.J., or Climagro, Leco Industries, Inc., Quebec, Canada) or brown (Polyon-Barkai, Poly West, Encinitas, Calif.) These mulches warm up the soil like clear mulch but without the accompanying weed problem.

An above-ground spectral response exists in addition to the response t o elevated soil temperatures, and may be physio-chemical (e.g. phytochrome regulation) or radiative (e.g., increasing or decreasing the heat load on the foliage). For example, in a pepper canopy, twice as much reflected photosynthetically active radiation (PAR) was measured above clear plastic mulch than above black plastic or bare soil. Although both red and black plastics raised soil temperatures similarly, higher early yields and less foliage were observed in plants grown on red plastic. Both red and black mulches reflected about the same amount of PAR, but red plastic increased the ratio of red:far-red wavelenghts (R:FR) in the reflected light. The R:FR ratio and the amount of blue light reflected toward the canopy apparently are critical. In turnips, blue and green mulches induced longer leaves and higher shoot:root ratios than white mulch. The R:FR ratio reflected from white plastic is lower than that of sunlight. Additional colors that are being investigated currently are red, blue, yellow, gray, and orange, which have distinct optical characteristics and thus reflect different radiation patterns into the canopy of a crop, thereby affecting plant growth and development. This light reflectivity can affect not only crop growth but also insect response to the plants grown on the mulch. Yellow, red, and blue mulches increased green peach aphid populations, and the yellow mulch, which attracted increased numbers of striped and spotted cucumber beetles and Colorado potato beetles. Yellow has long been used in greenhouses to monitor the population of insects. Mulches with a printed silver surface color have been shown to repel certain aphid species and reduce or delay the incidence of aphid-borne viruses in summer squash. Similar to a white mulch, the degree of opacity of a gray mulch may require a herbicide or fumigant to be used to prevent weed growth. Some of these colored mulches (blue and red) had a dramatic impact on the soil temperatures, raising soil temperatures to 167 and 168° F, respectively, at the 2-inch depth when the ambient air temperature was 104° F.

At the Center for Plasticulture extensive research is being conducted on different formulations and well as colors of plastic mulches and their impact on plant growth and yields both in the field and in high tunnels. Results of this research and publications on this topic will be found in this section of the website.

Summary and Recommendations for the Use of Mulch Color in Vegetable Production

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For additional information regarding plasticulture or the Penn State Center for Plasticulture, log on to the following web sites.

http://www.plasticulture.org - American Society for Plasticulture

plasticulture.cas.psu.edu - The Penn State Center for Plasticulture

When purchasing polyethylene film for use in the production of vegetables in the field, there are several characteristics of the polyethylene that users must consider for specific applications. Film thickness spans the entire range from 0.015 mil to 1.5 mil; the thinner films requiring specific applicators to place the film in the field, to the thicker films which would last for 2 years or a triple cropping sequence. Opacity of the film (how much light will pass through the plastic) will govern both the amount of radiation which will heat the soil and the growth of weeds under the film. The last characteristic which growers have to decide is mulch color: black, white, silver, red, blue, brown, IRT (infrared thermal), green IRT and yellow. Each of the colors will produce specific temperature (both soil and ambient) and light modifications within the micro-environment of the raise-bed/plant canopy.

Over the last 10 years, we have conducted extensive testing of the affect of mulch color and various vegetable crops. Some generalities that can be made regarding color are: 1) silver repels aphids, 2) blue attracts thrips - has been very effective in greenhouse tomato production and 3) yellow attracts insects. There also appears to be some reduction in disease pressure with crops grown on specific colors. Based on years of field research at the Horticulture Research Farm, Rock Springs, PA, the following colors are recommended for specific crops.

Tomato - this crop appears to respond more to red mulch compared to black with an average 12% increase in marketable fruit yield over a 3 year period. There appears to be a reduction in the incidence of early blight in plants grown on red mulch compared to plants grown on black mulch. When environmental conditions for plant growth are ideal, tomato response to red mulch is minimal.

Pepper - this crop appears to respond more to silver mulch compared to black with an average 20% increase in marketable fruit yield and fruit size over a 3 year period. Lowest yield of marketable pepper were harvested from plants grown on either white or light blue mulch at this location. In more southern climates, below North Carolina, pepper response to white mulch would be entirely different. Pepper plants grown on green IRT had similar marketable fruit yields compared to plants grown on black.

Eggplant - this crop appears to respond more to red mulch compared to black with an average 12% increase in marketable fruit yield over a 2 year period. Greatest response of eggplant to red mulch observed when plants were growing under stress conditions (temperature and water). There may be a varietal response of eggplant to the use of plastic mulch.

Cantaloupe - this crop appears to respond more to green IRT or dark blue mulch compared to black with an average 35% increase in marketable fruit yield over a 3 year period. Lowest yield of marketable cantaloupe were harvested from plants grown on either white or black mulch at this location. In more southern climates, below North Carolina, cantaloupe response to white or black mulch would be entirely different.

Cucumber - this crop appears to respond more to dark blue mulch compared to black with an average 30% increase in marketable fruit yield over a 3 year period. There was a difference in yield response between an open-pollinated and hybrid variety. Lowest yield of marketable cucumber were harvested from plants grown on yellow mulch at this location. In more southern climates, below North Carolina, cucumber response to yellow mulch may be entirely different.

Summer Squash - this crop appears to respond more to dark blue mulch compared to black with an average 20% increase in marketable fruit yield over a 2 year period. Lowest yield of marketable zucchini squash was harvested from plants grown on yellow mulch at this location. In more southern climates, below North Carolina, cucumber response to yellow mulch may be entirely different.

Onion - this crop appears to respond more to several different mulch colors including red, metalized silver and black compared to no plastic mulch with an average 24% increase in marketable bulb yield over 8 varieties. There was a significant difference in yield response between specific onion varieties and mulch color. This trial evaluated red onions, but other onion types should respond similar to the red onion varieties grown in this mulch trial.

Potato - this crop appears to respond more to several different mulch colors including red, metalized silver and black compared to no plastic mulch with an average 24% increase in marketable tuber yield. While there was no significant difference in yield response between the mulch colors, potatoes grown on the metalized silver mulch can have the highest marketable tuber yields, coolest soil temperature and least number of Colorado Potato beetle adults. However, the metalized silver mulch can be difficult to lay in the field and obtain a tight fit over the raised bed. Compared to black or red plastic mulch, the metalized silver mulch in cool years may also have the lowest plant population of potatoes because of poor plant emergence. There was a significant difference in yield response between specific potato varieties and mulch color. Use of black or possibly red plastic mulch will produce the highest yield of quality potatoes.

How Scientists are "Tricking" Plants Colored Mulch Research

http://www.plasticulture.org - American Society for Plasticulture

plasticulture.cas.psu.edu - The Penn State Center for Plasticulture

Background

Plants are very competitive organisms. They are always competing for space, nutrients, sunshine, and water. Plants must endure hardships such as disease, insects, and weather. They must have defense mechanisms and sensory structures to battle these environmental factors. Plants also have to battle each other. They have a way to detect each other and a method to compete with their surrounding neighbors. Plants have a substance called phytochrome that acts as a sensor to detect changes in the color of light that is reflected from the surrounding environment. Plants use light as a signal that enables them to compete with their surroundings. They do not know if the signal is a neighboring plant, dead plants on the surface of the soil, or even the color of the soil. The plant recognizes far-red light as the signal. If the plant detects an abundance of far-red reflection, it thinks that there must be other plants growing nearby. The phytochrome will then signal the plant to put more energy (photosynthate) in the top of the plant (shoot) instead of in the bottom of the plant (roots). The plant, in effect, is trying to outgrow its competition.

What Is Colored Mulch?

If you have ever picked strawberries, you have seen the black plastic that covers the soil of each of the rows in a field. Farmers have used black plastic for years to reduce the amount of weeds near the crop, to warm the soil in early spring, to keep soil from drying out, and to prevent the soil from splashing on the fruit. Because this plastic is black in color, it will absorb the sun's energy and keep more heat underneath the plastic. Since researchers knew that different colors reflected different wavelengths of light, they began to ask questions like, "Would other colors increase plant growth, but provide the same favorable conditions as the black plastic?" The researchers decided to devise some other colors of plastic. This plastic with various pigment combinations is called colored mulch.

What Does Colored Mulch Do?

Colored mulch mimics the reflective patterns of the green leaves of neighboring plants. The plant will sense the increased ratio of far-red to red light as though it is reflected from the nearby plants, when in fact it is just the colored mulch. The colored mulch "tricks" the plant into putting more energy into shoots to outgrow other plants. Some colored mulch even "tricks" the plant into producing more and better tasting fruit.

How Did the Scientists Actually "TRICK" the Plants?

Plastic mulch only came in black, white, or clear. In order to make the other colors, the scientists first used paint to convert the black plastic to other colors. The scientists then measured the reflection from colored plastic with an instrument called a spectrophotometer, which records the amount of light at different wavelengths reflected off the plastic. The scientists grew tomatoes in soil covered with different colors of mulch to see what would happen next.

What Were the Results?

Tomatoes that were gown over red plastic had larger shoots and smaller roots than plants gown over other colored plastic such as white or black. Since the plastic keeps the soil moist and protected, a slightly smaller root would not harm the plant. For tomatoes, using the red colored mulch gave a 20% increase in the first harvest of tomatoes. This is important to farmers because the first fruit of the season can bring in the most money. For all crops, the key is the amount of far-red light that is reflected. In plastic mulch plots, the plant senses an increase of far-red light and will put more energy into the shoot and less into the root. Therefore, if the fruit is produced in the shoot, it will usually be larger.

Have Scientists Used Any Other Plants in Their Research?

Scientists have also done research with strawberries, turnips, peppers, peas, beans, and cotton. They have used colored mulch to determine if other plants will try to outgrow each other, or put more energy in their shoot. They found certain colors of reflected light can change the flavor of some fruits and edible roots (such as turnips and carrots).

Why Is this Research Important?

When colored mulch is used in agriculture, crops are expected to produce larger fruit and possibly even better tasting fruit. This could mean larger and better tasting fruits and vegetables in grocery stores or in home gardens.

University of Connecticut
INTEGRATED PEST MANAGEMENT IPM

THE USE OF DIFFERENT COLORED MULCHES FOR YIELD AND EARLINESS

Plastic mulches have been used commercially on vegetables since the early 1960s. Three basic mulch types have been used in commercial production: black, clear, and white-on-black plastic. Plastic mulches directly impact the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss. The color of a mulch largely determines its energy-radiating behavior and its influence on the microclimate around a vegetable plant. Color affects the surface temperature of the mulch and the underlying soil temperature. The degree on contact between the mulch and soil, often quantified as a thermal contact resistance, can affect greatly the performance of a mulch. If an air space is created between the plastic mulch and the soil by a rough soil surface, soil warming can be less effective than would be expected from a particular mulch.

The soil temperature under a plastic mulch depends on the thermal properties (reflectivity, absorbitivity, or transmittancy) of a particular material in relation to incoming solar radiation. **Black plastic mulch**, the predominate color used in vegetable production is an opaque blackbody absorber and radiator. Black mulch absorbs most UV, visible, and infrared wavelengths of incoming solar radiation and re-radiates absorbed energy in the form of thermal radiation or long-wavelength infrared radiation. Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch increases soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Because thermal conductivity of the soil is high, relative to that of air, much of the energy absorbed by black plastic can be transferred to the soil by conduction if contact is good between the plastic mulch and the soil surface. Soil temperatures under black plastic mulch during the daytime are generally 5^{o} F higher at a 2-inch depth and 3^{o} F higher at a 4-inch depth compared to those that of bare soil.

In contrast, **clear plastic mulch** absorbs little solar radiation but transmits 85% to 95%, with relative transmission depending on the thickness and degree of opacity of the polyethylene. The under surface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation, so much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus, daytime soil temperatures under clear plastic mulch are generally 8 to 14^{o} F higher at a 2-inch depth and 6 to 9^{o} F higher at a 4-inch depth compared to those of bare soil. Clear plastic mulches generally are used in the cooler regions of the United States, such as the New England states. Clear mulch is used primarily in the our region of the country because it provides an even warmer soil environment --a mini-greenhouse effect-- that allows the early production of sweet corn and other crops. Using clear plastic mulch will require the use of a herbicide, soil fumigant, or solarization to control weeds.

White, **coextruded white-on-black** or **silver reflecting** mulches can result in a slight decrease in soil temperature -2 ^{o} F at 1-inch depth or -0.7^{o} F at a 4-inch depth compared to bare soil, because they reflect back into the plant canopy most of the incoming solar radiation. These mulches can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial. Depending on the degree of opacity of a white mulch, it may require the use of a fumigant or herbicide because of potential weed growth.

The newer family of **highly reflective silver** mulches have been used primarily to repel aphids and thus delay the onset of virus symptoms in a fall squash crop. The soil temperatures under these mulches will be several degrees (5-8° F) cooler when compared to a black plastic mulch. In research on the effect of mulch color on yields of Irish potatoes, silver mulch had the highest yields when compared to red, black or bare ground. This may have been due to the silver mulch providing a cooler soil environment which favors potato growth and development.

Another family of mulches includes the **wave-length-selective** or **photoselective** mulches, which selectively transmit radiation in some regions of the electromagnetic spectrum but not in the photosynthetic wavelength. These mulches absorb photosynthetically active radiation (PAR) and transmit solar infrared radiation, providing a compromise between black and clear mulches. These infrared-transmitting (IRT) mulches afford the weed control properties of black mulch but are intermediate between black and clear mulch in terms of increasing soil temperature. The color of these mulches can be blue-green (IRT-76, AEP Industries Inc., Moonachie, N.J., or Climagro, Leco Industries, Inc., Quebec, Canada) or brown (Polyon-Barkai, Poly West, Encinitas, Calif.) These mulches warm up the soil like clear mulch but without the accompanying weed problem.

Newer colors that are currently being investigated are **red**, **yellow**, **blue**, **gray**, and **orange**, which have distinct optical characteristics and thus reflect different radiation patterns into the canopy of a crop, thereby affecting plant growth and development.

Red mulches were the first really new color to be investigated, other than the ones mentioned above and have started to be used commercially. There have been alot of trials on tomatoes, some that have shown a benefit either of improved yields or enhanced ripening and quality of the fruit. In other trials, there has not been a response. There is also some indication from different trials that red mulch may also be reducing the severity of early blight on tomatoes. This is indeed an interesting finding that may have some real benefit. Red plastic mulch has also been shown to increase yields in zucchini and in honeydews and muskmelons. In a study in New Hampshire, researchers found that differences in reflectivity among a red, black and red on black mulch were minimal at 16 inches above the mulch surface and on the shaded side of the row. They speculate that for red mulch reflectivity to have a more sustained and more consistent effect on biomass accumulation and yield in tomato, the rows may need to be oriented in a North-South direction.

A summary of two years research at Penn State on crop response to red, brown IRT, green IRT, black, silver, white, blue (light and dark) and yellow color mulch is presented below:

1. **Tomatoes.** No significant difference in the yield of marketable tomato fruit (cv. Sunbeam) from clear, yellow, black, silver, red or brown IRT mulch.
2. **Peppers**. No significant difference in yield of marketable peppers fruit (cv. Enterprise) from clear, yellow, black, silver, red and brown IRT mulch. Fruit grown on yellow produced the smallest fruit. Silver, red and clear mulch appeared to hasten maturity of the peppers harvested compared to the black or yellow treatments. In 1998, plants grown on silver mulch significantly produced more marketable pepper (cv. Marengo) compared to those grown on white mulch. There were no significant differences in marketable pepper among the other colors (green and brown IRT, black, red, yellow and blue). Pepper plants grown on either silver or green IRT mulch produced larger fruit compared to brown IRT, black, red, white, yellow or blue mulches. Highest soil temperature, taken on August 3, 1998, was recorded under green IRT mulch 103 ° F and coolest under white (89° F).
3. **Muskmelons.** Plants (cv. Cordele) grown on green IRT, blue, red, silver mulch produced significantly more fruit (total yield) than plants grown on white mulch. In addition, plants grown on green IRT or blue mulch produced significantly more fruit compared to plants grown on black

mulch. Larger fruit was harvested from plants grown on brown IRT mulch and the smallest from plants grown on black mulch.

4. **Zucchini and honeydew**. Blue-colored mulch improved yields of zucchini, honeydew.

This light reflectivity can affect not only crop growth but also insect response to the plants grown on the mulch. Examples are yellow, red, and blue mulches, which increased green peach aphid populations, especially the yellow color, which attracted increased numbers of striped and spotted cucumber beetles. There may exist the potential to use this information in developing an insect management program where a row of yellow mulch is laid in the field after a certain number of rows of whatever mulch is being used for the crop. It would be considered a trap row. In a trial in Pennsylvania, the highest yield of peppers was from yellow mulch. Since, it has been proven that insects are attracted to this color, a grower has to really be on top of their scouting for insects. Yellow has long been used in greenhouses and now in high tunnels to monitor insects.

Similar to a white color mulch mentioned previously, the degree of opacity of these newer colored mulches may require a herbicide or fumigant to be used to prevent weed growth. Some of these colored mulches, for example blue and red, can have a dramatic impact on the soil temperatures, raising soil temperatures to 167^{o} and 168^{o} F, respectively, at the 2-inch depth when the ambient air temperature was 104 ^{o} F (my research in Kansas).

Summary. There are still many aspects of colors that we really do not understand. We know that we can build a mulch to specific spectral parameters or wavelengths and that will determine the color. The color of the mulch will influence the soil temperature, the surface temperature of the mulch and the light reflected by into the plant canopy. We know the blue color in the 440-495nm wavelength band will cause a plant response- phototropism, photosynthesis; while red color in the 625-800nm wavelength band will influence photosynthesis, seed germination, seedling/vegetative growth, and anthocyanin synthesis. Another impact on the effectiveness of a color is if the mulch is applied to a raised bed or is laid flat on the ground. This can cause a difference in the impact a mulch can have on the soil and plant microenvironment. The last consideration is the difference in color retention, film appearance, and film longevity of mulches currently on the market. This is the critical question of what really is a red, blue or yellow mulch and how best do we define it. To anyone who has ever look at a color additive chart, the problem is readily apparent. A lot more research still needs to be done on the effect different colors have on the microclimate, vegetable crop growth, yields and earliness.

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menu

Weed Management in Vegetables

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Weeds compete with crops to reduce yields and affect crop quality. In vegetables, weeds can cause severe yield reductions and can delay or interfere with harvesting of vegetables if left uncontrolled. Common methods to control weeds in vegetables include mechanical, cultural, and use of herbicides (chemical). Use of mechanical or physical and cultural methods is applicable in organically produced vegetables and is also effective in small farms and home gardens. Herbicides are effective tools to manage weeds in commercial vegetable production using IPM tactics.

Mechanical or physical weed control involves hand weeding, use of mulches, or simple machinery like hoes, cultivators, mowers, flamers, etc. Hand weeding is expensive but can be very effective in early-season weed control. Mulches used to control weeds include straw, newspaper, plastic, and grass clippings. When mulching with organic materials, it is important to mulch deep enough to conserve soil moisture as well as block weed emergence. Most organic mulches keep the soil cool, and thus will not result in early harvest of most vegetables.

Plastic mulches are becoming popular for vegetable weed control in both home gardens and commercial fields. Mulches block light so weeds do not germinate. In addition, the plastic keeps the soil warmer (black mulch) or cooler (white mulch) and reduces evaporative loss of water. Natural products such as vinegar, clove oil, corn gluten, etc. are also becoming available for weed control in organically grown vegetables.

Cultural methods are also practiced in some situations which involve use of competitive and smother crops, use of allelopathic cover crops, and crop rotation. A popular cultural method for controlling weeds in vegetables is the stale seedbed technique. With the stale seedbed method, the soil is tilled approximately two weeks before the expected seeding date, and weeds are allowed to germinate and emerge under optimal soil moisture and temperature. The emerged weeds are then tilled into the soil or burned down with a non selective herbicide such as glyphosate prior to planting the crop.

Biological weed control involves the use of natural enemies to reduce the weed populations which might include parasites, predators or pathogens specific to certain weeds. However, current economics and short shelf life of the biological agents make biological control a relatively less popular method.

Weed Control in Organically Grown Vegetables – Research at West Virginia University

Research was conducted at WVU to evaluate different non-chemical options to manage weeds in vegetables. Under irrigated conditions, hand-cultivated plots and plastic mulch plots resulted in similar levels of pepper yields (Table 1). However, plastic mulch increased pepper yields by an average of 100%, compared to plots that received hand-cultivation, or 8" straw mulch, respectively in non-irrigated pepper (Table 2). In this study, twenty-fold pepper yield increases were noted in plastic mulch plots compared to untreated plots (weedy check). Hand-cultivated plots and plastic mulch plots resulted in similar root dry weight of pepper, but ten-fold increases of root dry weight were noted compared to untreated plots, however, roots were 35% longer in pepper grown on plastic mulch plots compared to hand-cultivated pepper. Corn gluten applied at 80 lbs/1000 sq. ft. reduced weed counts by 78% at 3 weeks after treatment, however, the weeds that germinated outgrew the crops to cause severe yield reductions (data not shown). Directed application of vinegar to actively growing weeds provided >90% control of young actively growing broadleaf weeds but did not translate to yield benefits in peppers due to crop injury, grass competition, and germination of broadleaf weeds after vinegar application.

Directed application of vinegar (12.5% acetic acid) was also evaluated for weed control in potatoes. Broadleaf weeds were lower in vinegar-treated plots compared to untreated plots. Grasses and sedges were suppressed for two to three weeks following vinegar application but exhibited re-growth later. Hand cultivation resulted in 63% higher yields compared to untreated plots, whereas, a directed spray of vinegar, or at the low application rate during early and late growth stage resulted in 36% higher tuber yield compared to untreated plots (data not shown).

Table 1. Effect of physical weed control methods in irrigated pepper.

Treatment	Pepper yield -- lb/plot --	Pepper number (per plot)	Shoot dry wt (lb/plot)
Hand Cultivation	36.7	175	1.5
Plastic Mulch	38.7	199	2.0
Straw Mulch (2 in)	3.7	31	0.3
Straw Mulch (4 in)	13.9	78	0.5
Straw Mulch (8 in)	6.0	38	0.6
Control	0.1	10	0.0
Hand Cultivation	22.8	101	1.4
Plastic Mulch	28.7	146	2.1
Straw Mulch (2 in)	2.4	25	0.3
Straw Mulch (4 in)	9.3	66	0.5
Straw Mulch (8 in)	6.3	43	0.5
Control	6.8	48	0.1
L.S.D (P=0.05)	11.8	49	0.1

Table 2. Effect of weed control methods in non-irrigated pepper.

Treatment	Pepper yield (lb/plot)	Pepper number (per plot)	Shoot dry wt. (lb/plot)	Root length (in)	Root dry wt. lb/plant
Hand Cultivation	32.3	321	1.6	4.4	0.007
Plastic Mulch	51.7	655	2.6	6.9	0.007
Straw Mulch (2 in)	11.1	173	0.7	4.5	0.004
Straw Mulch (4 in)	7.6	152	0.5	3.7	0.003
Straw Mulch (8 in)	20.7	285	1.2	5.1	0.006
Control	2.7	21	0.1	2.8	0.004
L.S.D (*P*=0.05)	8.4	104	0.3	0.6	0.003

Chemical Weed Control in Vegetables

Herbicides are often used for weed control in commercial vegetable production. They are marked by savings in farm labor, effective weed control, and reduction in production costs. Herbicides registered in vegetables are tested for crop tolerance and residues by the IR-4, a governmental agency that assists the EPA to register herbicides in specialty crops. If herbicides are used according to the label guidelines and are included in an integrated approach (IPM) to control weeds they enhance the production capability of a grower. Growers should be careful to read the label thoroughly before using herbicides in vegetables because of potential crop injury. Misapplication (broadcast vs. row middle), application at the wrong timing (before crop emergence vs. after crop emergence), crop stage (seedbed vs. transplants) etc., can affect crop safety significantly. Use of non-selective herbicides such as glyphosate may be carried out very carefully using a hand held wick-applicator if necessary to minimize injury from spray drift. Prior to herbicide application, spray equipment used to apply herbicides in vegetables should be washed thoroughly using a detergent solution to rinse off residues from previous pesticide applications. Herbicides registered for common vegetables in West Virginia along with some general guidelines for their use are listed in *Tables 3-5*.

Table 3. Chemical weed control recommendations for Pepper.

Herbicide (Trade Name)	Rate of Application (Product/A)	Application Timing	Weeds Controlled	Comments
Napropamide (Devrinol 2EC)	*2 -4 qt*	Pre-emergence (Pre-plant incorporated)	Annual grasses and broadleaves.	Shallow incorporation is required. Follow label for rotational restrictions.
Clomazone (Command)	*0.67 to 2.67 pt*	Pre-emergence to transplants	Annual grasses and few broadleaves.	Not to be used in banana peppers. Weak on pigweed. Apply prior to transplanting. Place roots of transplants below chemical barrier. Avoid drift.
Halosulfuron (Sandea)	*0.5 to 1 oz*	Pre-or Post-emergence to weeds.	Pre: Annual broadleaves Post: Yellow nutsedge and most annual broadleaves.	Apply to row-middles when applied Post-emergence to crop.
Sethoxydim (Poast 1.5L)	*1.0 to 1.5 pt*	Post-emergence	Annual grasses.	Apply to actively growing grasses.
Carfentrazone (Aim 1.9 EW)	*0.5 to 2.0 oz*	Post-emergence	Young, actively growing broadleaves. Does not control grasses.	Apply to row middles using a shielded sprayer (no crop contact). Apply prior to transplanting.

Table 4. Chemical Weed Control Recommendations for Tomato.

Herbicide (Trade Name)	Rate of Application (Product/A)	Application Timing	Weeds Controlled	Comments
Metribuzin (Sencor DF)	*0.33 – 0.67 lb*	Pre-emergence (Pre-plant incorporated) Or Post-emergence	Annual broadleaves and few grasses.	For use in transplants only. Limit to 1.3 lb/A per season.
Napropamide (Devrinol 2EC)	*2 -4 qt*	Pre-emergence (Pre-plant incorporated)	Annual grasses and broadleaves.	Shallow incorporation is required. Follow label for rotational restrictions.
Metolachlor (Dual Magnum)	*0.67 to 2.67 pt*	Pre-transplant or Post-transplant within 2-3 days	Annual grasses, yellow nutsedge, galinsoga, few other small seeded broadleaves.	No incorporation necessary.
Rimsulfuron (Matrix 25 WP)	*2.0 oz*	Pre-emergence or Post-emergence	Annual grasses and few broadleaves.	Post-emergence application requires an adjuvant (crop oil or NIS).
Halosulfuron (Sandea)	*0.5 to 1 oz*	Pre-or Post-emergence to weeds.	Pre: Annual broadleaves Post: Yellow nutsedge and most annual broadleaves.	Post-emergence applications require at least 2 weeks after transplanting. Max. of 2 applications/season.
Sethoxydim (Poast 1.5L)	*1.0 to 1.5 pt*	Post-emergence	Annual grasses.	Apply to actively growing grasses.
Carfentrazone (Aim 1.9 EW)	*0.5 to 2.0 oz*	Post-emergence	Young, actively growing broadleaves, does not control grasses.	Apply prior to transplanting. Apply to row middles using a shielded sprayer (no crop contact).

Table 5. Chemical Weed Control Recommendations for Potato.

Herbicide (Trade Name)	Rate of Application (Product/A)	Application Timing	Weeds Controlled	Comments
Metribuzin (Lexone or Sencor DF)	*0.33 – 1.33 lb*	Pre-emergence	Annual broadleaves and few grasses.	Limit to 1.33 lb/A per season.
Pendimethalin (Prowl 3.3 EC)	*1.2 – 3.6 pt*	Pre-emergence	Annual grasses and few small seeded broadleaves.	Prowl H2O, new formulation has no stain. Check label for rates.
Dimethanamid (Outlook 6 EC)	*12 – 21 oz*	Pre-emergence after planting	Annual broadleaves and few grasses.	Shallow incorporation is required. Follow label for rotational restrictions.
Metolachlor (Dual II Magnum)	*1.0 to 2.0 pt*	Pre-transplant or Post-transplant after hilling	Annual grasses, yellow nutsedge, galinsoga, few other small seeded broadleaves (will not control germinated weeds).	Total must not exceed 3.6 qt/season.
Rimsulfuron (Matrix 25 WP)	*2.0 oz*	Pre-emergence or Post-emergence	Annual grasses and few broadleaves.	Post-emergence application requires an adjuvant (crop oil or NIS).
Sethoxydim (Poast 1.5L)	*1.0 to 1.5 pt*	Post-emergence	Annual grasses.	Apply to actively growing grasses.
Carfentrazone (Aim 1.9 EW)	*0.5 to 2.0 oz*	Post-emergence	Young, actively growing broadleaves and a few grasses.	Apply to row middles using a shielded sprayer (no crop contact).

For further information concerning vegetable herbicides, consult the *Commercial Vegetable Production Guide for West Virginia*.

Hand Tools

Specialty Garden Hoes (Texas Gardener)

Comparison Chart of Various Hoes from Peaceful Valley (Peaceful Valley)

Specialty Hoes from Johnny Seeds (Johnny Seeds)

Glaser Wheel Hoe (Market Farm Implements)

The Hoss Wheel Hoe

Websites for Hand Tools (UMaine)

TEXAS GARDENER
The magazine for Texas Gardeners, by Texas gardeners ®

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Specialty Garden Hoes

A New Look at an Old Gardening Tool

By Skip Richter
Contributing Editor

Weeds are unfortunately a part of gardening. I'd like to tell you that I don't allow them in my garden but I don't think you'd buy that one for a minute. The irritating thing is that we go to such great links to make our desirable flowers and vegetables survive and grow while weeds just thrive all on their own. Even when we make an attempt on their life, they seem to recover and bounce right back. Someone once said, "If you see a plant growing and wonder if it is a weed or a flower, pull it up. If it comes back, it was a weed."

I must confess that I've had an ongoing lifelong battle against weeds. Weeds and I, well we have a history. From my childhood years of having to pull weeds as punishment for misbehaving (let's just say that we had the most weed free garden in town.) to hoeing miles of peanut rows in the summers as a teen to make a few bucks, I've been a weed hit man for as long as I can recall.

There are just a few options for managing weeds in the garden. Preventing them with mulch is a good start and offers several additional benefits as well as that of deterring weeds. Herbicides are a second option. Most gardeners don't bother with the pre-emergence products as they are not all that simple to apply at correct rates and must be watered in properly to activate. Plus the trend is away from chemicals toward a more natural approach to gardening. This leaves physical control, i.e. hand hoeing and cultivating.

This article will focus on the old fashioned approach of hoeing weeds. Forget your old memories of chompin' up the dirt to weed the garden. Forget too the blisters, calluses and back aches of too much time spent stooping over to grub or pull out weeds. If you've been hacking up dirt with a standard garden hoe you are in for a pleasant surprise. There are some old and some new tools that make weeding easier, faster and more effective.

Get What You Pay For
Now I know it's an old adage but in the long run you really do get what you pay for. Cheap tools break, fall apart, and often don't work well to begin with. Not all hoes are made the same. Manufacturers cut corners in a number of ways. The most common is at the place where the metal blade joins with the handle. This point is the spot where the greatest pressure is exerted and where the tool is most likely to come apart.

Some hoes attach with a shank that extends from the blade up into the handle. A metal sheath is then wrapped around the base of the handle. This creates a weak connection that will come apart in time. Better quality tools create stronger connections where the blade and the piece that wraps around the handle is all one piece of metal. They also allow for easy changing of the handle should it ever break.

The basic garden hoe design is the least expensive. As you get into unique specialty hoes the price goes up considerably. Just remember that a quality hoe will last a lifetime if provided good care. Plus all those years of use will be in easier and more effective weeding work. Anyone who has purchased pocket knives, pruners or power tools knows that a quality tool is the best long term investment.

Types of Hoes
Let's take a look at some of the improvement in hoe design over the years. First we can divide hoes into two categories, those that move soil and those that simply remove weeds. The traditional standard garden hoe is designed to do a little of both. Despite its popularity it is not the best hoe for either job. A heavier duty version of the standard garden hoe is called a Nursery Hoe.

Soil Moving & Shaping
Soil moving hoes have larger blades. Some hoes may have a blade shape designed to facilitate a special soil moving function. Examples of soil moving hoes are the raised bed hoe (with wide blade for forming and shaping beds) and the potato hoe (designed for hilling up potatoes).

Another function of soil moving hoes is for forming trenches. The Warren hoe has an arrowhead or triangular shaped design with the point of the arrowhead downward making it useful for forming small furrows. It also may be used to tamp down the soil after seeding. The Warren hoe doubles duty as a weeding hoe for digging beneath a larger weed to pry up the roots.

The Korean hoe has a blade that curves inward and ends in a sharp point. It is also useful for forming a furrow or for digging beneath a larger weed to remove it roots and all. The heavy bladed eye hoe, sometimes referred to as a grub hoe, is also useful for trenching and for removing larger weeds.

Easy Weeding
The best time to remove a weed is when it is still young. The older and larger it gets the more effort you'll spend trying to remove it. While still young weeds can be easily destroyed (don't you just love the sound of that word?) with the thin blade of a hoe moving horizontally just below the soil surface.

This disrupts the soil the least and thus eliminates the weed without bringing new weed seeds to the surface to set you up for a major invasion in round two. It is also much easier. The act of chopping down hard, pulling up soil, lifting the tool, and chopping again is a lot of work. Your back and hands feel the strain and without gloves blisters are sure to come.

In addition to weed control when you slice horizontally just under the soil surface it cultivates the soil, breaking up the crusty surface layer. This broken surface acts rather like a mulch in that it slows evaporation from the lower parts of the soil while improving aeration and water infiltration during a light rain.

Hoes that move horizontally just below the surface can be operated with little effort and while standing upright. A gardener can cover a lot of ground in a short time. And if I can side track here a moment I'd like to offer something else to consider. Weeding this way is therapy. You spend a little time outdoors in fairly mindless work in which you can get a lot of thinking done about whatever is going on in your life. Then in a short time you look back over the row or bed you just completed and the results of your work are immediately evident. There is a simple kind of satisfaction in a task with such immediate and dramatic before and after results.

There is a tendency for us gardeners to operate long handled garden tools using our backs to push or pull as we lean forward and back. We also tend to stand stooped over as we work. After a while in doing such work in such a position your back will really let you know it is not happy with the arrangement!

Instead, start by standing up straight with legs apart shoulder width and knees bent just slightly. I have a couple of good techniques that work well for me. The first is to grip the handle with the hand on the same side of your body as the tool handle at your waist and your other hand in front of you with both thumbs pointed down toward the blade end of the handle. Use your arms to push and pull the hoe or cultivator through the soil.

An alternative technique is to place the hand on the tool handle side of your body up at shoulder height and place the other hand at about waist height with both thumbs pointed up toward the end of the handle. The action is more like sweeping to the side and just in front of you. It may seem awkward at first but it works well once you get the hang of it, and it keeps you from stooping. These techniques only work with hoes designed for slicing horizontally just below the surface as opposed to garden, nursery or eye/grubbing type hoes.

Top Choices for Weeding
There are a lot of specialty hoes on the market designed for working the soil surface to remove weeds. Each has its advantages but I've found that most experienced gardeners usually have one or two favorite designs depending on the job. A few cut on the push stroke, some on the pull stroke and others cut on both strokes. Here are a few of the more common specialty hoes that are designed for controlling weeds while they are still very small. Should you let the weeds

get ahead of you, then you're back to choppin' away with a standard type hoe.or using my favorite technique: Mow, Rototill, and Start Over!

Oscillating Hoe
(Also called Stirrup, Scuffle, Action and Hula Hoe)

This hoe has a stirrup-like strap of metal sharpened on both edges which pivots slightly back and forth at the point of attachment. It is used in a push and pull action rocking back and forth across the soil.

You can cover a lot of ground quickly with an oscillating hoe. It is not the precision weeding tool that some hoes are but it is very efficient and great for cultivating as you weed.

Collinear Hoe
The unique collinear hoe has a long, narrow rectangular blade. It is used in a sweeping motion alongside your body with the handle very upright. Using a collinear hoe is kinda like shaving your garden soil to remove the weeds! The sharp thin blades are usually replaceable and work well on soil that is reasonably prepared. These types of hoes don't work well in hard soil with large clods.

Swan Neck/Half Moon Hoe
The design of these hoes is a curved arching neck with a fairly narrow blade that has a curved top and a straight cutting edge. They slice on the pull stroke only. The sharp pointed edges are great for getting into tight places to get at weeds. They are used in a sweeping motion alongside your body with the handle at a very upright angle to the soil.

Diamond Hoe
This hoe has a wide narrow diamond shape with sharp edges on all four sides and long narrow points on the left and right ends of the diamond shape. It is used with both push and pull action in a sweeping motion. Some models have an offset "T-handle" (also called a pistol grip) at the end of the long handle for using in a motion similar to using a hand saw. The diamond hoe is sometimes also called a scuffle hoe as are other hoes with varying shapes such as triangular, which are sharpened on all sides and travel flat to the soil just beneath the surface.

Stirrup/Loop Hoe
This is the second hoe that goes by the name stirrup hoe but it is quite unlike the oscillating hoe. These tools have a continuous loop of metal that is flattened into a sharp blade along the base edge. They are good for working in close around plants and provide the advantage of making it easier to see where the edge of the tool's cutting surface is. This avoids a few "oops."

Circle Hoe
This is quite similar to the stirrup and loop hoes except that the blade is a flat circular piece of metal sharpened on both edges. The tool is easy to use and makes weeding around plants fast and goof proof too.

This is certainly not an exhaustive list of the many specialty hoes on the market. There are a number of variations on many of these hoes and additional hoes by other names including onion hoe (wide narrow blade for close work), pointed push hoe (push & pull slicing), cavex hoe (similar to standard hoe but with curved blade edge), and the Dutch scuffle hoe (a push hoe).

Tool Care
Provide a quality tool good care and it will last for years. Whenever you finish using a hoe wash it off to remove any dirt. If your soil is heavy clay a flathead screwdriver or wire brush may be needed to remove the sticky soil. Dry the blade promptly after washing.

Spray the metal parts with a product like WD-40 or wipe them with oil to prevent rust. Once in a while sand any wooden handles lightly to smooth them if they are becoming rough. An occasional wipe down with linseed oil will also help keep the wood in good condition.

Some gardeners use a 5 gallon bucket 3/4 full of coarse sand to clean and oil their hoes, shovels, spades and other tools. Pour a quart of oil into the sand. Then push your tools into the sand a few times to clean any remaining dirt off and to apply a thin coat of oil to their surfaces. Remove the tools and wipe off excess oil and sand. You can also leave spades and shovels stuck down into the bucket of sand as a storage container.

Keep your hoes sharp for easier, more effective weeding. Place the blade in a vise with the blade edge pointing up to hold it securely. I like to put on a pair of leather gloves just to be safe. Use a mill file to put a 30 to 45 degree angle on the blade. Use long smooth strokes downward or toward the blade. A mill file cuts in one direction, so only push the file against the tool blade on the down stroke. File the 30 to 45 degree angle on just one side of the blade. Finish by filing the opposite side with just a few very light strokes just to remove any burs that curled under when you were working the beveled side in order to leave a good sharp edge on the blade.

Don't be concerned if you aren't an expert at sharpening garden tools. Even if you don't do a superb job your hoe will work much better than had you not sharpened it at all, and you'll gain practice in the process!

Closing Thoughts...
Many of these hoes come in long handled and hand held sizes. Both come in very handy. While we focused on hoes in this article I can't help but mention that there are many other great garden tools for cultivating, and hand weeding. One such tool is a simple little hand tool called the Cobrahead Weeder which is great for loosening soil for setting out transplants, working around plants to remove weeds and for forming a seeding furrow.

Visit a good full service garden center in your area to see what types of hoes and other weeding tools they carry. There are many brands and styles on the market at a wide range of prices. If you have trouble finding these specialty hoes in your area the sources list that accompanies this article lists mail order companies that carry many of these tools.

SOURCES

A. M. Leonard, Inc. 241 Fox Drive P.O. Box 816 Piqua, OH 45356-0816 (800) 543-8955 www.amleo.com	Action Hoe (an Oscillating type hoe) Eye Type Grub Hoe EZ-Digger (a Korean Hoe) Warren Hoe
Lee Valley Tools Ltd. P.O. Box 1780 Ogdensburg, NY 13669-6780 Orders (800) 871-8158 Customer Service (800) 267-8735 www.leevalley.com	Circlehoe (hand held size) Collinear Hoe Diamond Hoe Loop Hoe
Index Innovations, Inc. 6534 Tunnel Loop Road Grants Pass, OR 97526 (800) 735-4815 www.circlehoe.com	Circlehoe (several sizes)
Gardener's Supply Company 128 Intervale Road Burlington, VT 05401 (888) 833-1412 www.gardeners.com	Cobrahead Weeder Diamond Hoe Swan Neck Hoe
Johnny's Selected Seeds 955 Benton Avenue Winslow, ME 04901 877-Johnnys (877) 564-6697	Collinear Hoe Garden Hoe (quality design with replaceable trapezoid shaped blade and stronger attachment to the handle than most) Stirrup Hoe (an Oscillating Hoe)
Earth Tools, Inc. 1525 Kays Branch Road Owenton, KY 40359 (502) 484-3988 www.earthtoolsbcs.com	Collinear Hoe Diamond Hoe Oscillating Hoe Raised Bed Builder Swan Neck Hoe Upright Hoe (standard garden type hoe with a replaceable trapezoid shaped blade

and a stronger attachment to the handle than most)

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Name	Application	Cost	Working Position
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The **Real Wheel Hoe** is a top quality Swiss made hand push between-row cultivator. A variety of tools are available including the stirrup and sweep type cultivators in many working widths. Two models of hand push frames are available. The **Pico** is the small frame that will only handle single mount tools centered on the frame. The **Berg** is the deluxe and most popular model that will accept all of the tools, as well as the dual wheel kit for straddling narrow rows. Made in Switzerland, we import both models with the original galvanized handles for long lasting durability.

Pico	$325.00	**Hiller, 8"**	$48.00
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The HOSS Wheel Hoe - Made in the USA

Our wheel cultivator is Built Strong to last for decades.

Weeds garden rows twice as fast as a conventional hoe

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An affordable reproduction of the time-tested Planet Jr. Wheel Hoe.

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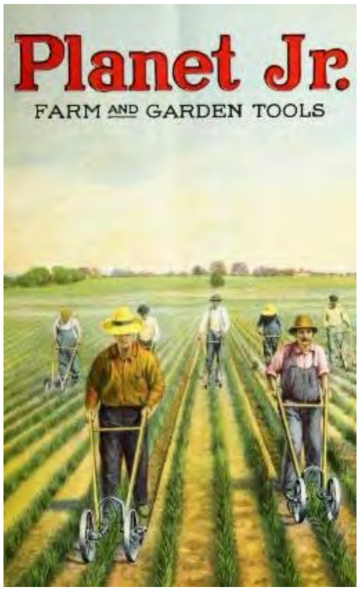

A great tool for large gardens! The time-tested easiest way to cultivate and weed your rows and paths.

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MODEL	PRICE	DESCRIPTION
Standard PLUS Wheel Cultivator	$149	Single wheel cultivator with 3 cultivator teeth
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Double Wheel Conversion Kit	$50	One additional wheel, extra long axle, and fasteners
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But in the 1950's market gardening started to quickly lose ground
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Hoss Tools was started by two bright market gardeners who were
frustrated with the poor quality of garden tools available in

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The wheel cultivator has been used for so many generations for one reason: it works great!

When your garden is too big for hand hoeing and too small for a tractor, the wheel hoe is the tool to use. It is the easiest way of manual cultivating

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The Standard PLUS is a great garden cultivator.

Supplied with cultivator teeth only.

The wheel cultivator can till and loosen your garden soil in preparation for planting. Used as a garden cultivator it will aerate and loosen the soil around established plants. When used for weeding it will quickly uproot larger weeds and bury smaller weed seedlings.
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Double wheel versions contains BOTH single and double wheel axles for easy conversion!

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Includes the Hoss Tools 1-year Warranty
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The Hoss Deluxe PLUS Wheel Hoe is a classic row weeder
AND a great push cultivator

Comes complete with weeding blades and cultivator teeth

Our weeding blades are exact copies of the Planet Jr blades that were used so successfully for so many decades. They are also called Sweeps because the blades
angle back to allow cut weeds to clear the blades. This is the same efficient design

used on 1000's of tractor drawn weeders.
By slicing shallowly just beneath the surface (about 1/2" deep) they kill young weeds
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Blade position is easily adjustable to weed paths from 12" to 7" wide

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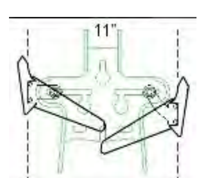
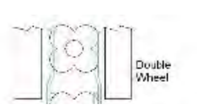
A double wheel hoe creates superb balance while it straddles the row of crops. This allows

the weeding blades to remain level and steady
while they work both sides of the crop row in one pass.
See how it weeds both sides of the row

Click any of the wheel hoe images to the right to see wide range of useful ways





Double Wheel Hoe Cultivator

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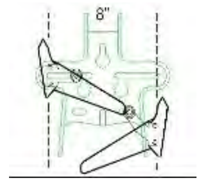

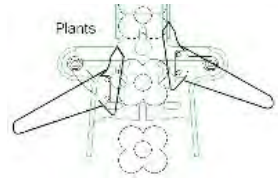

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All parts will also fit on matching Planet Jr wheel hoe models.

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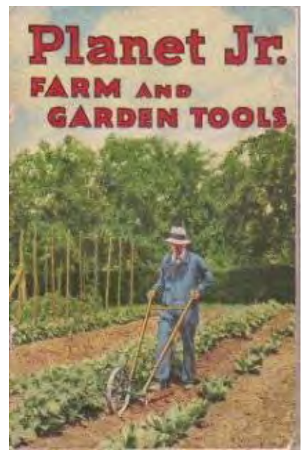

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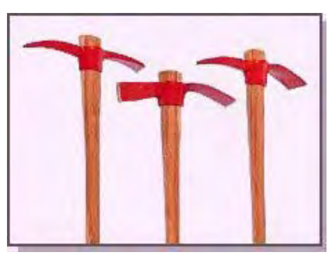
Click here to see the Garden Cultivator / Wheel Hoe Assembly and Usage Instructions

Click here to read the Double Wheel Conversion Instructions



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From **Weed Ecology at University of Maine**
(http://www.umaine.edu/weedecology/weed-management/manufacturers-and-suppliers/cultivation-equipment.html)

The sites listed below feature tools that may be of interest to small- to mid-scale diversified vegetable producers, and are for informational purposes only, no endorsement is intended or implied.

- Circlehoe
- DeWit Tools
- Elomestari
  Finnish manufacturer and dealer of the Weed Master
- Holdredge enterprises, LLC
  Hooke 'n Crooke weeders
- Johnny's Selected Seeds
  Maine supplier of seeds and equipment. > see Tools and Supplies for a range of hand hoes and wheel hoes;
- Fedco
  Maine supplier of seeds and equipment. Organic Growers Supply division offers hand tools in their catalog.
- Peaceful Valley Farm & Garden Supply
  California organic agriculture supplier with a wide range of hand tools.
- Lee Valley Tools
- Peje-plast
  Manufacturer of the LUCKO hand weeder
- HOSS Wheel Hoe
- Planet Whizbang Wheel Hoe
- Four Wheel Hoe
- Maxadyne Wheel Hoe
- Red Pig Tools
- Valley Oak Tool Company
- Market Farm Implement
  Pennsylvania dealer of Real Wheel Hoes, and a wide range of tractor-mounted cultivators
- Red Dragon (flame weeding)
- Flameweeders.com
  Wheel-mounted, shielded, push flamer with 4- or 5-torches.

Resources for Cultivation

Steel in the Field: A Farmer's Guide to Weed Management Tools (SARE)

Organic Weed Control: Cultural & Mechanical Methods (ACRES)

Cultivation Equipment for Weed Control: Pros, Cons, And Sources (Univ. of Vermont)

Use of Mechanical Cultivators for Market Vegetable Crops (Agri-Food Canada)

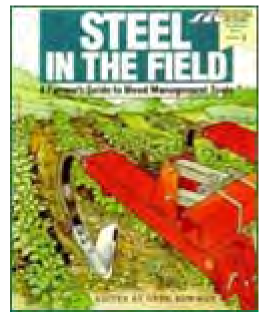
New Cultivation Tools for Mechanical Weed Control in Vegetables (Cornell IPM)

Vegetable Farmers and their Weed-Control Machines (Univ. of Vermont)

Did this book prompt you to make any changes to your farming operation? This and other feedback is greatly appreciated!

Steel in the Field: A Farmer's Guide to Weed Management Tools

Book



Let's face it -– controlling weeds remains the no. 1 challenge facing producers across America. Trying to do so with few or no herbicides presents an even tougher battle.

In some ways, cultivating for weed control is almost a lost art. Herbicides seemed to work so well for so long that many farmers abandoned mechanical means of control. Today, farmers are employing many techniques to control weeds, including careful selection of crops in rotations, using cover crops to compete with and smother weeds and, of course, mechanical cultivation. With new implements and improved versions of the basic rotary hoes, basket weeders and flame weeders of 50 years ago, we are seeing improved efficiency.

Steel in the Field: A Farmer's Guide to Weed Management Tools provides information about how each implement works, rates each tool's usefulness in certain conditions, identifies problems other farmers have faced and how to get more information. First published in 1997, this revised 2002 version includes updated tool sources with World Wide Web sites, updated contact information for experts and current tool prices.

This is the first tool-centered book to combine farmer experience, commercial agricultural engineering expertise and university research. It directly tackles the hard questions of how to comply with erosion-prevention plans, how to remain profitable and how to manage residue and moisture loss.

Farmers -– 22 of them –- do a lot of the talking, sharing their struggles and successes with tools, weeds, herbicides and cropping systems.

Organic Weed Control

Cultural & Mechanical Methods

Corn (next to a field of oats/peas/barley) that has recently been cultivated for the second and last time with a high-clearance cultivator.

Peter Martens, cultivating soybeans on a John Deere 3020 with JD725 front-mount cultivator and a IH133 rear-mount cultivator, both with C-shank teeth. The front has half sweeps, the back has sweeps. The front cultivator is modified to have two gangs per row instead of the standard single gang in the middle of the row. The rear cultivator is modified with a side shifter to keep it aligned with the front cultivator on side hills.

by Mary-Howell & Klaas Martens

Weeds happen. That is a fact of life for organic farmers, and therefore many of our field operations are designed to make sure that the health and quality of our crops are not jeopardized by the inevitable weed pressure. Planning an effective weed-control program involves many different aspects of organic crop production. As farmers begin to explore organic possibilities, the first two questions invariably seem to be: "What materials do I buy for soil fertility?" and "What machinery do I buy to control weeds?" We asked these questions when we started organic farming, but we rapidly realized that this is not the best way to understand successful organic farm management.

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To plan an effective weed-control program, you must integrate a broad spectrum of important factors, including your soil conditions, weather, crop rotations and field histories, machinery, markets and specific market quality demands, and available time and labor. You must have the ability to adjust your weed-control strategies to the unique and ever-changing challenges of each year. Above all, you must be observant, and, in the words of William Albrecht, you must learn "to see what you are looking at."

CULTURAL WEED CONTROL

Do you think that weeds just happen, that there is little you can do to limit your weed population other than cultivate? Then think again! Before you even think about cultivating, there are many things that you can actively do to change field conditions so that they favor crop growth and discourage weed pressure. Cultural weed control is a multi-year, whole-farm, multi-faceted approach — and you are probably doing much of it already without realizing the effect your actions have on weed pressure.

Writing in 1939, German agricultural researcher Bernard Rademacher stated, "Cultural weed control should form the basis for all weed control," and that "the other various means should be regarded as auxiliary only. The necessary condition for any successful weed control is the promotion of growth of the crop species. Vigorous plant stands are the best means for eradicating weeds." The same wisdom must be applied to organic agriculture today, actively incorporating the philosophy that good agronomic practices that result in vigorous, competitive crop plants are the real key to successful weed control.

Many agronomic procedures that encourage healthy soil conditions with a diverse microbial population can also reduce weed pressure. Optimizing the biological terrain of the soil for the crop will create an unfavorable environment for many weeds, effectively reducing weed numbers and vigor. This concept forms the core of effective weed control in an organic production system.

Contrast this to the weed-control strategies of conventional farming, with heavy use of salt fertilizers, herbicides, monoculture and imbalanced cation saturations. Indeed, that environment could accurately be described as one of cultural weed *enhancement*. The conventional field environment presents heavy pressure to select for herbicide-resistant weeds that thrive under these conditions. Each year, these highly adapted weeds find the same favorable conditions and reproduce abundantly. It is really no wonder that most herbicides are only effective for a few years before a newer, stronger (and more expensive) chemical is needed to control weeds sufficiently.

It is important to know your enemy. All weed species have their weaknesses and their strengths, usually occurring at distinct stages of their life cycles or resulting from specific growth patterns. Different weeds present problems at different times of year, or with different crops. Some weed-control strategies, such as disking a field infested with quackgrass, may even increase the prevalence of certain species of weeds under specific conditions. Grassy weeds often require different control measures than do broad-leafed weeds. Correctly identifying the species of weeds that are causing major problems in your fields is critical to choosing and timing effective control measures. It is valuable to have a good weed-identification book and use it regularly during the season until you are confident recognizing your most common and troublesome weeds.

While no factor can truly be viewed as separate, it is important to examine some of the primary management concepts that contribute to effective cultural weed control.

1. Crop Competition. The most effective way to control weed growth is to have highly competitive crops. A vigorously growing crop is less likely to be adversely affected by weed pressure. It is imperative to create conditions where the intended

Lely weeder.

crop can establish dominance quickly. Using high-quality, vigorous seed, well-adjusted planting equipment, adapted varieties, optimal soil fertility, good soil drainage and tilth, and proper soil preparation will usually result in rapid, vigorous crop growth.

2. Soil Fertility & Condition. In an organic system, it is important to rely on the biological activity of the soil as the main source of fertility and favorable soil physical structure. An active and diverse soil microbial population is the key to growing healthy, high-yielding organic crops. Successful organic fertility management should primarily feed the soil microbial life in a long-term manner, rather than simply feeding the plants. Soil organic matter is a tremendous source of plant nutrients and water-holding capacity. Soil tests can be useful, but only if the results are interpreted appropriately for an organic system. Careful attention to the balance of key nutrients can often reduce weed problems and enhance crop plant growth. One common mistake made by many organic farmers is the improper application of manure or improperly finished compost. This can throw off the balance of certain soil nutrients and microbial life and can often increase weed growth. Some soil fertility amendments, such as gypsum, can increase the looseness and tilth of the soil. This improves success for mechanical-cultivation operations, but it also seems to reduce the pressure from certain weed species that are favored by hard, tight soils.

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3. Crop Rotation. Diverse crop rotations are essential to build a healthy, sustainable organic system and break pest and weed cycles. In general, it is best to alternate legumes with grasses, spring-planted crops with fall-planted crops, row crops with close-planted crops, heavy feeders with light feeders. Careful use of cover crops during times when the ground would be bare adds valuable nutrients (especially nitrogen), adds organic matter, improves soil microbial diversity, and prevents erosion. Maintain a long-term balance of diverse crops on a farm, taking into account any necessary soil conservation practices, livestock requirements, time constraints and market profitability.

4. Allelopathy. Some plant species compete with each other by releasing chemical substances from their roots that inhibit the growth of other plants. This "allelopathy" is one of nature's most effective techniques of establishing plant dominance. Allelopathic crops include barley, rye, annual ryegrass, buckwheat, oats, sorghum, sudan-sorghum hybrids, alfalfa, wheat, red clover and sunflower. Selecting allelopathic crops can be useful in particularly weedy fields with reducing overall weed pressure.

5. Variety Selection. Careful selection of crop varieties is essential to limit weeds and pathogen problems and satisfy market

Cultivating corn, with view of IH133 rear-mount cultivator with C-shank teeth.

needs. It is important to consider planting disease-resistant varieties if certain pathogens are prevalent in the area. Any crop variety that is able to quickly shade the soil between the rows and is able to grow more rapidly than the weeds will have an advantage. Deep shading crops, which intercept most of the sunlight that strikes the field and keeps the ground dark, will prevent the growth of many weed species. Alfalfa, clover and grasses are particularly good shading crops because any weeds that grow in them will usually be cut when hay is harvested, thereby preventing weed seed production.

6. Sanitation. Using clean seed will prevent the introduction of new weed problems and will avoid planting a generous crop of weeds with your desired crop. Mowing weeds around the edges of fields or after harvest prevents weeds from going to seed. Hand-roguing weeds in problem areas, and thoroughly composting manure can reduce the spread of weed seeds and difficult weed species. Thorough cleaning of any machinery that has been used in weedy fields is a good idea, as is establishing hedgerows to limit wind-blown seeds. Common sense, yes — and it works!

Cultural practices won't prevent all weed growth, and some mechanical follow-up will usually be necessary, but cultural practices can improve soil conditions, permitting more effective mechanical control, they can adjust weed species to ones that are easier to control, and, most importantly, cultural weed-control practices can produce high-quality, vigorous, high-yielding organic crops.

MECHANICAL WEED CONTROL

We like to consider mechanical weed control as consisting of four distinct phases, each one very important to the overall success of your weed control program. The *point* in early mechanical weed control is to create as large a crop-to-weed size differential as possible, as early as possible, so that row cultivation is most successful. When crop plants are bigger and more vigorous than the weeds, the weed pressure will usually not jeopardize the crop. Therefore, effective early weed control, before weeds present a visible threat to the crop, is absolutely essential.

Tillage

Appropriate tillage of fields is critical:

1. To create a good seed bed for uniform, vigorous crop emergence.

2. To prepare the ground adequately for successful subsequent mechanical weed control operations.

3. To eliminate much of the weed potential.

When it is possible, initial tillage a week or 10 days before planting will allow the resulting flush of germinating weeds to be killed during final field preparation. Organic gardeners call this technique "stale seed bed." Weed seeds are stimulated to germinate by the first tillage, then they are killed by the second, final field preparation. Many organic farmers find that in heavily infested fields, late spring plowing will reduce weed pressure by killing weeds that have started to grow and burying many germinating weed seeds.

Plowing can have a different positive effect by inverting weed seeds that have started to germinate down deeply where they won't grow, and bringing other weed seeds that have not yet been stimulated to germinate to the surface. By the time these new weed seeds "get the message" to germinate, you can already have your crop growing.

It is important to note that weather conditions dictate how effective tillage is in controlling weeds. Naturally, the best weed control will be achieved with tillage on a hot, sunny day. Tilling soil that is too wet will result in compaction and loss of soil structure, which will then favor certain types of weeds that prefer hard ground and will also make later cultivation less effective. Wet weather following tillage may result in weeds re-rooting. Cold, wet conditions following initial tillage may also slow weed seed germination, reducing the effect of stale seed bed.

If the soil breaks up into large clods when plowing, weed seedlings may be protected within the clods and not killed by the tillage. If the ground is worked wet, and clods are formed during tillage, this will make subsequent mechanical weed control much more difficult.

When tillage is done on a sunny, warm day, troublesome weeds with long underground rhizomes, such as quackgrass, can be dragged to the surface and will dry out. Dragging a field with a spring tooth harrow can pull many of these rhizomes to the surface. This old technique can effectively rid an infested field of quackgrass if done several times.

To Till or Not to Till — that seems to be the burning question in American agriculture these days. Excessive tillage can result in soil erosion, breakdown of soil structure, a shift in microbial activity and loss of organic matter, and it uses consid-

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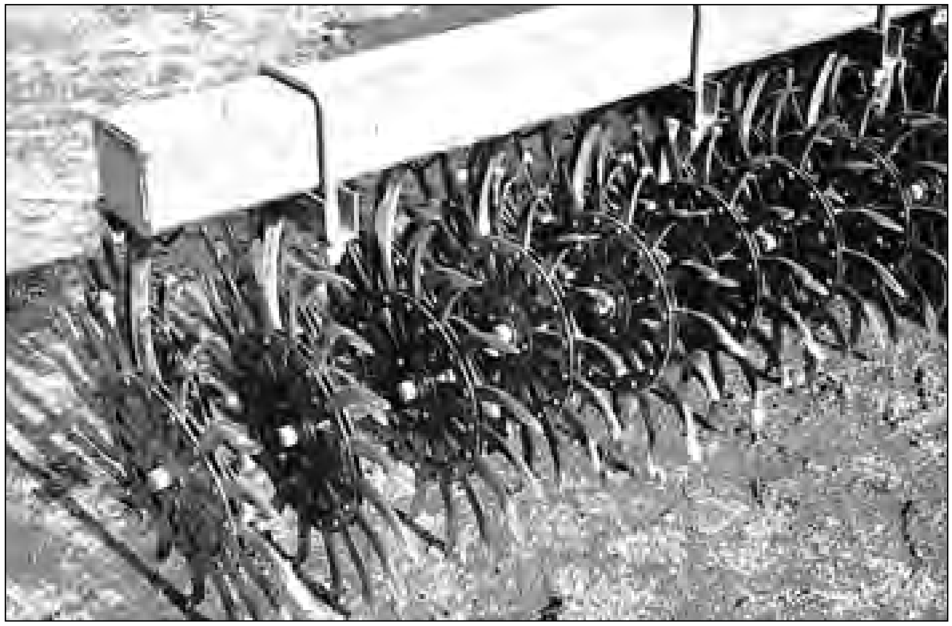
erable amounts of fuel and tractor time — this does not mean you should go out and invest in massive quantities of Roundup, however. Sometimes it seems that the current popular infatuation with no-till often amounts to little more than institutionalized support of Monsanto's profits. Not all soils, not all crops, and not all farms are well suited to no-till. After all, there is a well-known saying here in New York: "No till, no corn!"

Organic farmers *can* and *should* incorporate reduced tillage practices into their techniques. You do *not* have to plow every year, nor do you have to use herbicides to get the benefits of reduced tillage. Many crops — such as small grains, clover and grass hay — can be successfully planted in untilled or lightly tilled soil. Anne and Eric Nordell in Pennsylvania are no-till planting garlic into growing oats in the fall. The oats winterkill, forming a thick mulch that prevents weed problems in the garlic in the spring. Planting into a living crop, like the oats, provides continuous physical cover to the soil, and there is less soil damage by winter rains and snow than if the ground were bare. This helps maintain good soil pore space and healthy microbes during a vulnerable period for the soil.

There are many creative ways that organic farmers can incorporate reduced tillage into their operations, but we should not feel guilty about occasional plowing. Mixing the soil will redistribute nutrients and make them available to crop plants. The introduction of air into the soil is also important, especially in an organic system that relies on microbial activity to provide soil fertility. With the introduction of new oxygen, the soil microbes are able to digest soil organic matter, to convert it into stable humus, and to reproduce, releasing readily available nutrients into the soil solution which our crops will use. While some soil organisms may be harmed by the physical action of plowing, for many species and for plant roots this breath of fresh air is just what they've been waiting for. To organic farmers, the most important value of soil organic matter is its use as a source of fertility — and our friends the microbes need oxygen to do that.

The most successful no-till systems that we know of are actually being "bio-tilled," using plant roots and animals like earthworms to actively till the soil instead of machinery. We have fairly good success with no-till broadcasting small grains, like spelt and wheat, into fields of living soybeans in early fall. The grains are well started by the time the soybeans are harvested. This success is consistent with other successful organic no-till systems we've seen, where a new crop is planted into a still-living old crop, and where there are living roots and active soil microbial conditions. This is a much different biological environment than when a broad-spectrum herbicide is used to kill all living plant material in the field, and the ground is left bare over winter.



Rotary hoe.

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"Carbon sequestration" is a real buzzword in conventional ag circles, the justification for promoting no-till/Roundup technology. If all you want to do is sequester the maximum amount of carbon in your soil and raise your soil organic matter, then burying fence posts would probably be your best bet. However, if you want the soil organic matter to be an active source of fertility and to support an active, diverse microbial population, then these tiny aerobic (oxygen-needing) organisms need air. Both Sir Albert Howard and Neal Kinsey have observed that there is a rapid loss of soil organic matter after soil becomes anaerobic due to excessive water or compaction. Plowing adds new air to the soil, releases the buildup of waste gases, mixes nutrients and organic material around in the soil, and when the plowing is not so excessive as to cause compaction, it helps to loosen soil and produce good soil-pore space for air and water holding capacity.

Remember that where no-till techniques are used, subsequent mechanical weed control options are more limited because of trash and because the soil may not be loose enough. Therefore, it is really critical to have your cultural weed control strategies in good shape before trying any no-till options.

PLANTING THE CROP

Few farmers realize that a well adjusted planter is one of their most valuable weed control tools. Uniform, proper placement of the crop seed will result in even vigorous growth. Don't assume that just because a planter has shiny paint, it is doing a good job! And remember to use cleaned, high-vigor seeds for rapid, strong emergence.

You should regularly get off the tractor and dig up the seed to check the accuracy of the planting and make adjustments if necessary. This should be done not only in the good locations in the field but also in lumpy, uneven or unusual areas too. Planting into wet or particularly lumpy soil should be avoided. Older corn planters with worn seed discs, gauge wheels, closing wheels or other parts can result in uneven planting. Worn parts should be replaced or repaired.

Kovar coil-tine harrow.

The planter frame and units should also be regularly inspected to insure they are not bent or warped. Retrofitting with shoes, firming points, specially designed seed tubes or "eccentrically" (on an angle) bored gauge wheel bushings will often result in more uniform seed placement than what the planter had when it was new. Trash wheels in front of the gauge wheels will sweep away clods and stones, making for a level surface and therefore uniform planting.

BLIND CULTIVATION

"Blind cultivation" is the easiest and best opportunity to destroy the weeds that would be growing within the rows and presenting direct competition to the crop. In blind cultivation, the entire field is tilled shallowly with the implement, paying little attention to where the rows are.

The point of blind cultivation is to stir the top 1 to 2 inches of soil, adding air and causing the millions of tiny germinating weed seeds to dry out and die. The larger crop seeds germinate below the level of the cultivation and are not usually damaged by this operation. Weed seedlings are very vulnerable to drying out and to burying at this stage, and by doing an effective job of blind cultivation, you can achieve the biggest possible crop/weed size differential from the start. Blind cultivation also can break a soil crust, allowing crop seedlings to emerge.

Usually, the first blind cultivation pass is done right before crop emergence, with a second pass done about a week later, depending on conditions. The most effective blind cultivation is done when the soil is fairly dry and the sun is shining, a wind also improves the effect.

There are a number of implements that can be used for blind cultivation. Coil-tine harrows, rotary hoes, Lely weeders and Einböck tine harrows are some examples of useful tools that organic crop farmers use.

The Kovar coil-tine harrow has either regular straight tines, or new tines that are bent on the ends and the angle to the soil can be adjusted changing the aggressiveness. A 45-foot Kovar coil-tine harrow can actually cover the fields faster than a sprayer would and is very economical to operate.

Some organic farmers prefer to use the rotary hoe, going over the field the first time about three to four days after planting, and again five days later. Speed is a key factor in successful rotary hoe operation. A rotary hoe needs a high-horsepower tractor capable of moving at least 8-12 mph to be effective. Surprisingly, this does little damage to the young crop seedlings but destroys germinating weeds fairly effectively.

The Lely weeder works similarly by shaking the soil loose — killing small weeds but not harming the larger, deeper-rooted soybeans. The Lely weeder is very effective in breaking a surface soil crust. Do note, however, that the Lely can be rough on corn seedlings if it hooks the corn's branching root system.

There are other implements that do the same job of blind cultivation, such as the Einböck tine weeder. It pays to have several different tools on hand, so you can match the best tool to changing soil and crop conditions.

It is not uncommon to find inexpensive old, worn rotary hoes at auctions. Are they a good deal? Long before you think a rotary hoe is worn out, the teeth may be shorted, rounded and much less aggressive than new teeth. Such a rotary hoe will barely penetrate the ground properly, resulting in less dirt moved and few weeds killed. A good rotary hoe can be an expensive machine to maintain, but it is not essential to replace all the worn rotary hoe teeth. Since weeds growing between the rows will be controlled by later cultivation, you can economize by installing new rotary hoe wheels only directly over each row and leaving older wheels between the rows. Hoe bits can be welded to worn rotary hoe teeth to extend the life of the machine.

Weed species vary in their vulnerability to blind cultivation. Broad-leafed weed seedlings with their growing point above ground are easily killed when their tops are broken, while grasses with growing points below the soil surface need to be uprooted and desiccated. Most weeds are most sensitive to desiccation when they are in the "white hair" stage, early in germination. Established perennial weeds with deep roots and large reserves are not well controlled by blind cultivation and must be controlled by other methods.

Pounding rains can seal the surface of the ground, causing a crust to form. This problem can be especially troublesome on high magnesium or clay soils. Germinating crop seeds, especially legumes, can be trapped under the crust, unable to emerge or "breaking their necks" while trying to get through. A soil crust can also stimulate the germination of certain types of weeds. Ellen Chirco, seed technologist at the New York Seed Testing Laboratory, says that seeds of some plant species are stimulated to germinate by a buildup of carbon dioxide and ethylene in the soil, which results from improper air exchange and anaerobic conditions. Running a blind cultivation tool, like the coil-tine harrow or rotary hoe, through the field as a crust starts to form will often stop the hardening and thickening of the crust, allow crop seedlings to emerge, release some of the carbon dioxide and ethylene, let oxygen into the ground, and thereby slow the germination of some types of weeds.

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BETWEEN-ROW CULTIVATION

Effective early weed control, before weeds present a visible threat to the crop, is absolutely essential. The late-season weed control operations should be viewed as a follow-up, not as your primarily weed control. However, there are usually some escapes, and sometimes, unfortunately, there are lots of escapes. That's when it's time to set your cultivator correctly, drive straight and slow, and really pay attention to the details.

Front and rear view (before and after) of an older-style John Deere trip-shank cultivator. It is equipped with small shovels that allow the operator to cultivate very small crops at higher speed. This runs relatively shallow. This configuration is suitable for small weeds but not aggressive enough for large weeds or high weed populations.

When the crop rows are clearly visible and the corn plants are 8 to 10 inches tall — or soybeans are in the third trifoliate stage — it is time for between-row cultivation. Earlier cultivation may be necessary if a good crop/weed size differential has not been achieved, especially if weather has prevented your early season weed-control operations to be done optimally, but cultivation will go much slower and less aggressively when the plants are small because it is important to prevent the crop plants from being buried. In New York, two cultivation passes are usually required. The first pass is the most critical to determine the season's weed control, but the second is often necessary to eliminate the weeds that were stimulated to grow by the first cultivation, and to further aerate the soil.

There are rear-mounted and front- or belly-mounted models, and there are numerous types of cultivator teeth, shanks and points. Some farmers have tractors equipped with only a rear-mounted cultivator, while others get good control with a tractor equipped with both a front- and rear-mounted cultivator.

There are three main types of cultivator shanks:

Danish- or S-tine teeth will allow the greatest operating speed, they are not easily damaged by rocks, they will handle the most crop residue without plugging, and theyare relatively inexpensive. They do not penetrate as well in hard soil, however, and large rooted weeds may slip around the flexible teeth, thereby avoiding damage. Of different types of cultivator teeth, the operator has the least control over the action of the flexible Danish-tine teeth.

C-shank cultivator teeth are more rigid and give the operator more control. These may be the best for hard or rocky soil and for heavy infestations of quackgrass and other weeds with underground rhizomes. C-shank teeth are slightly more adjustable than the Danish-tine teeth.

Trip-shank teeth are the most rigid and require the slowest progress, but they give the operator superior weed control and adjustment ability. These are also the most expensive, large rocks can break the trip-shanks, and it takes a more experienced operator to make the necessary adjustments to get the full benefit of trip-shank teeth.

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There are many different types and widths of points that can be put on different cultivator teeth. Danish-tine teeth offer the least opportunities to vary point type, while trip-shank teeth offer the greatest choice. The most versatile type of points are probably half sweeps next to the row and full sweeps between rows. Each type of point works best under specific conditions and on certain weed species. For example, a type of point called a "beet knife" is particularly effective on nutsedge. Narrow spikes may sometimes be used to advantage to aerate waterlogged soil.

We use a double-cultivator arrangement, with trip-shanks on the front cultivator and half sweeps next to the row. The rear-mounted cultivator, which has C-shank teeth with full sweeps, covers the between-row area. While this combination is slower than a single Danish-tine cultivator, it gives excellent control of most types of weeds, even under an unfavorable crop/weed size differential. John Myer, in Romulus, New York, has had success with a rear-mounted Danish-tine cultivator with five shanks and 2.5-inch duck-feet points between each row. If the ground is hard, or if he has a quackgrass problem, he will instead use 1-inch spikes that are angled back to dig deeper. If he must cultivate when the soybeans are shorter than 7 inches, he will use half-worn teeth immediately next to the row.

Adjusting the cultivator to best fit the conditions is a fine art.

Relatively little adjustment is possible with Danish tines other than varying speed and depth and by changing the type of the points. With C-shanks, it is possible to change the angle to the soil and to the row slightly, but because they are springs, this adjustment changes in the soil as the cultivator moves. This is not a major problem when the cultivator is set deep and working between the rows, but it limits the success of controlling weeds within the rows. Trip-shanks allow wide adjustment of the angle of the points both to the row and to the soil.

Depth of the point is also easily adjusted. Because trip-shanks are rigid, the adjustments remain constant while cultivating. For example, by twisting the shank toward the row, a much greater amount of soil will be pushed into the row. Conversely, by twisting the shank away from the row, the soil thrown into the row is reduced. Changing the angle of the point to the soil can adjust for hard or soft soil. Under the right soil conditions, setting the points at an extreme angle to the soil can create a bulldozer effect, squeezing the crop row tightly with soil and thereby killing many weeds growing between the soybean plants and burying the rest.

Another logical but often overlooked point in successful cultivation is suggested by Cliff Peterson, a retired Yates County farmer, who remembers cultivating with horses when he was a boy. For the second cultivation in a field, Cliff suggests reversing the pattern/direction of the first cultivation. This alternating method can get weeds that were not fully removed in the first cultivation, and can compensate for gaps in cultivator coverage.

Plan on spending a lot of time when you first get out in the field adjusting the cultivator to get it to work right for the specific field conditions. As Cliff Peterson says, *"Almost* isn't good enough! Don't be satisfied with *almost!"* The first time through cultivating makes or breaks it — this pass will usually determine whether you are going to have a clean field or not. If you miss the weeds in the row the first time, cultivating more often later in the season will probably not make up for it. It's easy to get the weeds between the rows, but it takes real skill to get the weeds within the row. Cultivating works best when the ground is dry enough and in good physical condition. If you have to cultivate too wet, you can twist a piece of wire around the shovel and that will help break up the slabs of dirt as they flow over the shovel.

Critical Cultivator Adjustments:

1. Tractor speed — adjust constantly as you go across field.
2. Angle of the shovels, both laterally and horizontally to the row.
3. Depth of the shovels.
4. Down pressure on the gangs, if you have springs — this may need con stant adjustment, depending on changing field conditions.
5. Distance of the shovels from the row.

Adjustments will need to be done continuously through the day, as soil moisture and field conditions change, and as shovels wear or go out of adjustment. All rows need to be watched for adjustment needs. As you move along, watch *all* the rows, don't lock in on only one. If you don't watch all the rows, you can go along quite a distance before you realize something is wrong, by which time you've done lots of crop damage and missed lots of weeds. Carry a box of good tools on the tractor to make the adjustments easily and quickly, and carry common repair parts that may be needed.

It is essential to really focus on the rows and the job while cultivating, because even a slight drifting in the row can rapidly result in large sections of the corn or bean row being very effectively hoed out. Cultivating can be a very hot, boring job, especially when the crop plants are small. For the sake of the operator's health and attention span — and the health of the crop! — it makes a lot of sense to install a canopy on the tractor, bring a water bottle, and stop if you get sleepy.

It really helps to work with a farmer who is experienced with cultivating to learn and actually see how the dirt should flow, how much side pressure on the row is best, how much dirt should be pushed into the row to bury the weeds, how to make the proper adjustments, and to learn how hard you can treat the crop without hurting it.

One last word about cultivation and organic weed control: Trying too hard to get every last weed in a field can waste time, labor, and may actually do damage to the crop. Tractor operations after canopy closing will usually crush and tear crop plants excessively — and will probably be unnecessary, as shade from crop leaves will kill weeds trapped under the canopy. It is important to keep the whole crop in perspective, and not spend too much time making the first few fields immaculate.

Mary-Howell & Klaas Martens raise mixed grains on more than 900 acres in the Finger Lakes region of western New York, with every acre certified organic. Mary-Howell is a former genetics researcher and a frequent writer for Acres U.S.A. *They can be contacted by email at <kandmhfarm@sprintmail.com>.*

CULTIVATION EQUIPMENT FOR WEED CONTROL: PROS, CONS AND SOURCES

by Vern Grubinger
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Effective mechanical weed control requires compatibility among the crop, the soil, seedbed preparation technique and cultivation equipment. As you plant, so shall you cultivate: use row spacings that will accommodate your equipment with a minimum of adjustment. Cultivating in a timely fashion is important, but that can be a challenge because of weather or other farm management demands. When weeds get ahead of you, a 'rescue' strategy with aggressive cultivation tools and/or hand-hoeing may be needed.

Field Cultivators are used for pre-plant weed control as well as incorporating residues and preparing a seed bed. They have a rigid frame with several rows of S-tines or C-shanks attached in staggered fashion, fitted with sweeps or shovels. There may also be cutting discs, rollers, cultipackers, crop shields, leveling bars, spike harrows and/or gauge wheels attached to the frame. Field cultivators are good for keeping fields free of weeds, or 'bare fallowing', until crops are planted. They cannot be used for after planting, except in the case of narrow units pulled between wide rows. They are relatively heavy and not suited to small tractors. Several brands are available; they vary in size, tool configuration, available options, and cost.

The Perfecta II field cultivator is made by Unverferth Manufacturing. It comes in widths from 4 to 28 feet, with folding wings in wider models. The S-tines, spaced at 18 inches on 3 individual bars for 6 inch centers, are fitted with standard 2 3/4 inch sweeps. Heavy duty models have 7 inch sweeps and thicker S-tines. The latter lift more soil and require more horsepower to pull (60+ hp for 10 foot unit, depending on soil). The tooth leveling bar follows the tines; it comes with either diagonal spikes or straight spikes which are better with more trash or more clay. Then comes the crumbler roller which has 2 positions to vary aggressiveness. An 8 foot unit costs just over $2,000 with gauge wheels; add about $300 for heavy duty sweeps and tines.

Kongskilde, a Danish company and S-time innovator makes a unit called an 'S cultivator' that is manufactured in Canada. It has more tines and is priced higher than the Perfecta.. It comes in 7 to 12 foot widths, with 2 to 6 inch tine spacing. Available with leveling bar, crumbler rollers and either 'trailer' hockey stick harrows for leveling or long 'finger' harrows for stoney land. Brillion makes 'S-tine basket harrows' in 12, 15 and 18 foot widths. Stalford also makes a field cultivator, 3 to 42 foot wide with a variety of options.

Flex-tine weeders are used primarily for 'blind' cultivation over the whole surface of a recently planted field. They can be also be used before planting for bare fallowing. They're good at uprooting very small weeds but to avoid uprooting the crop must be several inches tall or have several true leaves. Some growers plant a little deeper to minimize crop damage. Tine weeders do not provide control of perennial weeds or well-established annual weeds.

Flex tine weeders can be used in clay or sandy soils and they work around rocks better than other blind cultivators. They can be used at fast speed, so the wider units cover a lot of ground quickly. Most units are light weight and can be used with small tractors. Originally intended for cultivating weeds in grain crops, flex tine weeders are suitable for use in many vegetable crops.

The Lely Weeder is made in Holland. It comes in 7, 10, 14 and 19 foot sections for about $1700 to

$3300. The 6 mm tines are set 1½" apart in 4 rows across the entire width of the unit, so it ‘floats’ independently. Optional gauge wheels help control depth, avoid gouging of soil on rolling land, and act as parking stands. It can be used as a blind cultivator with all the tines down until the crop is 3 to 8 inches tall, then the tines over the row can be raised and the cultivator used as a between-row cultivator. The depth of each individual tine can be adjusted, although few growers do so, instead using the 3-point hitch to adjust the pressure.

The Einbock Tined Weeder is made in Germany. Unlike the Lely, it has a single quick-adjust lever that controls angle and tension of all the rows of 7 mm tines. It is sold in 5, 6 and 10 foot sections for about $1600 to $2300. The 3-section unit can be manually folded; units with 3 or more sections fold hydraulically.

Rotary hoes are a more aggressive blind cultivator than tine weeders. They consist of thin spyder wheels 16 or 18 inches in diameter, set 3½ inches apart across the entire unit. The spiders turn independently and bear the weight of the unit; gauge wheels are available. Rotary hoes 6 feet wide cost about $1800, 12 feet wide cost $2600, available up to 24 feet. Originally intended for blind cultivation of grain crops, they can be used for control of small weeds in recently emerged corn or beans. They are good for breaking up crusted surface of soils. They work well in heavy soils but are not recommended for light soil because they are heavy and will work too deeply. Rocks can jam in the wheels, keeping them from turning properly, and possibly damaging the crop. Plastic mulch pieces in the field will also collect on wheels and require removal. Dull spyder tips reduce the effectiveness of rotary hoeing. John Deere and Yetter are manufacturers.

Basket Weeders are metal cages that roll on top of and scuff the soil surface without moving soil sideways into the crop rows. This action makes them ideal for newly emerged crops or crops like lettuce that have to be kept free of soil and are not suited to hilling. Buddingh basket weeders are custom built for two to eight row beds. Angled baskets are available to work the sides of raised beds. Basket widths range from 3 to 14 inches depending on the space between rows. For wider widths, and for inner row widths that change as crops grow, overlapping baskets are available that "telescope" or expand in and out to adjust for the width.

The front row of baskets turn at ground speed and a chain drives the rear row of baskets a little bit faster, so these kick up soil, and dislodge weeds that survive the first baskets. Commonly used at speeds of 4 to 8 mph, straight rows and an experienced operator are helpful to avoid crop damage. At higher speeds, both baskets will provide hoeing action. This tool is usually belly-mounted to facilitate close cultivation. The baskets handle small stones but work best in fine soils free of crop residues, and are most effective when weeds are very small, although they can take out a thick stand of inch-high weeds as long as the soil is friable. Cost is about $1400 for a 3-row unit on a 4-foot frame, depending on mounting hardware. Order well in advance.

Finger Weeders also known as Buddingh ‘C’ cultivators, are used to work around the stems of crop plants that are sturdy enough to handle some contact. Rubber-coated metal fingers provide some in-row weeding. These are connected to a lower set of metal fingers that work deeper in the ground and drive the unit at ground speed. These units are used at just a few miles per hour since they are in such close proximity to the plants. They require belly-mounting, and are ideal for a G-type tractor. Wet clayey soils can stick to fingers and require frequent removal. Cost is about $1500 depending on mounting hardware.

Sweep and S-tine Cultivators are used between rows on established crops. The shanks can be moved side to side on the toolbar to adjust for different row spacing and crop size. Sweep cultivators have C-shaped spring shanks, usually attached to 2½ inch diamond toolbars, often with gauge wheels at the ends of one toolbar. Hilling disks or other tools can be mounted close to the row. Cost for a 6 foot wide unit with 2 toolbars is about $1200 for 4 rows. Fewer, wider rows add to the cost as sweeps are added to work the between-row area. The spring shanks release when rocks are hit, then re-set.

S-tine cultivators have gangs of 3 tines attached to a 4 by 4 inch toolbar. Each gang floats independently on its own gauge wheel. They can cultivate row spacings of 16 inches or wider. Prices start at $850 for a 2-row unit or $1,500 for a 4-row unit on a 6 foot toolbar. Rolling crop shields or disc hillers add about $100 per row.

Sweeps, shovels and knives are tools that attach to the end of a shank. The type of tool, as well as the arrangement of shanks and toolbars determines the amount and direction of soil movement and the area that gets cultivated. Narrow shovels with sharp points uproot aggressive weeds like quackgrass. Half-sweeps work up close to the row or along the edge of plastic mulch. Tender hoes, beet hoes or side knives cut parallel to the soil surface, sideways under the crop canopy, allowing close cultivation. Crescent hoes work raised bed shoulders. Rusty tools they may not cultivate well and rusty clamps make adjustments difficult. Wasco Hardfacing Co. is one source of a wide variety of sweeps, knives, shovels, shanks and clamps.

Bezzerides Tools are spyders, torsion weeders and spring hoes, used alone or in combination for close between-row cultivation. The 12 inch spyder wheel has staggered curved teeth and is ground-driven, rotating on a ball-bearing hub. A pair spyders can be angled in or out to pull soil away from the row or throw it back. Aggressive and rapid cultivation of straight rows is possible, even on stony soils. Torsion weeders are square stock metal bars that minimally move soil next to emerging crops. They can lightly hill small crops or follow the spyders, leveling the soil and flexing around plants to clean up missed spots. Spring hoes are flat blades about 16 inches long. They are more aggressive than torsion weeders, traveling perpendicular to the surface and stirring soil just below ground alongside the root zone. Cost for all 3 tools is about $380 per row.

Rolling Cultivators consist of gangs of heavy slicer tines that aggressively dig up weeds and pulverize soil between rows. The gangs are ground-driven, and can be turned to adjust how much soil is moved.. Gangs can be angled one way to pull soil away from the row while the crop is small, then turned the other way to hill or throw soil into the row as crop gets larger, burying in-row weeds. The aggressive action can control rather large weeds.
Rolling cultivators can be used to work a crop like corn for as much of the season as the tractor can clear. Rear-mount, multiple row units are rather heavy and are not suited to small tractors. Individual gang width ranges from 10 to 16 inches depending on number of tines or spyders. A pair of gangs can be belly mounted to cultivate single rows; rear-mounted units can cultivate up to 12 rows. Several brands are available, including Lilliston, which start at $1,600 for a single row unit, up to $2,900 for a 4-row unit. Options can be added such as sweeps, crop shields, or fertilizer attachments for side dressing while cultivating. BHC and Brush Hog also manufacture a line of rolling spyders.

Williams Cultivator has a frame to which 4 rows of Lely flex tines are attached. It has a standard diamond front tool bar that attaches to the tractor with 3-point hitch. A second toolbar can be added behind the front tool bar to make room for more hilling tools, which is especially helpful if using it on 3 row beds. The flexible tines can be raised up about 12 to 15 inches off the ground; all of them or just the tines over a crop row, as needed. By removing two U-bolts you can remove the tine weeder frame, leaving the toolbar hitched to the tractor. That can be helpful once the clearance over the crop is limited; if you add the second toolbar it remains attached to the front one even when the frame is removed.

The tine weeders are good for 'blind' raking of the soil before crop emergence, and again for controlling small weeds after emergence, without damaging most crops. As the crops, and weeds, get bigger, more aggressive hilling action can be obtained by adding disks, spyders, shovels, and/or sweeps to the tool bar (s), customized to your needs. Since the tines are really effective only in the bed area, not in the wheel tracks, choose a frame size based on your tractor 'straddle'. The front bar length is usually designed to cover outside-to-outside of the tractor tires in order to allow tools to be mounted that will work the area behind the tires/ in between the beds. The tool system comes in 40, 50 and 60 inch frame sizes and the basic frame prices are $1680, $1800, and $1920. A second toolbar is $200, Gauge wheels are $200, and hilling spiders are $225. Available from Market Farm Implement.

Brush Hoes are made in Switzerland by Bartschi-Fobro. They are for close cultivation in narrow rows. Units are rather expensive, starting at $6,000 per row. Shields protect plants from bristle wheels that rotate independently between the rows, "sweeping" small weeds out of the soil and creating a ‘dust mulch’ that can suppress subsequent weed germination. An operator sits behind the rotating wheels and steers the unit to allow for close cultivation.

Star Hoes, also made by Fobro, are for cultivation between rows at least16 inches apart. They have gangs of ground-driven ‘stars’ that are much like the spiders on rolling cultivators, except the individual star ‘teeth’ are curved at the ends so as to lift soil more than other types of spiders. The gangs can be angled to pull soil away or push it into the rows. A second operator steers the unit as a whole over the rows, allowing very close cultivation. The unit is well suited to crops grown on beds in uniform row spacings, i.e. 17 inch triple rows, 34 inch double rows. Taller plants may not fit under the toolbar, and bushy plants may snag on the stars. These problems usually happen at the time a standard tractor has trouble clearing the crop. Price is about $4,500 for a 4-row unit without the steering mechanism for a second operator; it costs about $1,100 more. Stars can be added for additional rows, fertilizer units are optional.

Cultivating tractors are usually off-set for good visibility of the crop rows being cultivated. They may be lightweight and low to the ground for use on young or low-growing crops (the Allis Chalmers "G" tractor, no longer made, is the classic of this type) or high-clearance for taller crops (like Farmall Super A, Kubota, etc.). A 50 year-old cultivating tractor in good shape with implements may cost $3,000 to $4,000. High clearance cultivating tractors from the 1980's may cost $10,000. A new Saulkville cultivating tractor costs about $20,000.

Gauge wheels should be considered on rear-mounted cultivators so you can just drop the implement and watch where you are driving while cultivating. They help maintain uniform depth of cultivation and eliminate the need to set the tension with the 3 point hitch every time you set a cultivator down. They also make it quick and easy to park.

Some Sources of Cultivation Equipment

Bartschi-Fobro LLC
P.O. Box 651
Grand Haven, MI 49417
616-847-0300

Bezzerides Bros., Inc
P.O. Box 211
Orosi, CA 93647
559-528-3011

BDi Machinery Sales Co.
430 E. Main St.
Macunie, PA 18062

800-808-0454

Buddingh Weeder Co.
7015 Hammond Ave.
Dutton, MI 49316
616-698-8613

Chauncey Farm
119 Bridle Rd.
Antrim, NH 03440
603-588-2857

HWE Agricultural Technology (Einbock)
B.P. 1515
Embrun, ON K0A 1W0
613-443-3386

Market Farm Implement
257 Fawn Hollow Rd.
Friedens, PA 15541
814-443-1931

Lely Corp.
P.O. Box 1060
Wilson, NC 27894
252- 291-7050

Unverferth Manufacturing
P.O. Box 357
Kalida, OH 45853
800- 322-6301

Wasco Hardfacing Co.
P.O. Box 2476
Fresno, CA 93745
559-485-5860

Mention of brand name equipment, suppliers and prices is for information purposes only; no guarantee or endorsement is intended nor is discrimination implied against those not mentioned. This is not a complete list of cultivation equipment or suppliers. Prices are FOB estimates. (11/01)

RETURN TO VERMONT VEGETABLE AND BERRY PAGE

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Research Branch
Direction générale de la recherche

Canada

USE OF MECHANICAL CULTIVATORS FOR MARKET VEGETABLE CROPS

Horticultural Research and Development Centre (HRDC), Saint-Jean-sur-Richelieu, Qc

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April 2000

In a context of sustainable agriculture, producers endeavour to employ non-chemical control methods to manage weed infestations and protect the environment. Mechanical cultivators are an integral part of the weed management practices available as an alternative to herbicides.

For many fresh market vegetable crops, the range of registered herbicides is limited, and growers must rely on alternative weed management strategies when chemical control is not feasible. Mechanical cultivation is an environmentally friendly option of weed control and can help reduce expenses related to herbicide use.

For vegetable production, the decision to use a particular cultivator depends on a number of factors. Crop tolerance, weed control efficacy of each cultivator, the number of cultivation required, tractor speed and operating costs are all key factors that growers need to consider in choosing cultivators.

TYPES OF CULTIVATORS

In recent years, various types of more efficient cultivators have come onto the market. The new machines vary in their design, mode of operation and intervention window for cultivation (See chart on page 3). The description of the cultivators, their weed control efficacy and control strategies proposed in this factsheet are the results of a research project carried out by the Horticultural Research and Development Centre and McGill University on behalf of the Fondation québécoise pour la recherche en agro-foresterie, under the Canada-Quebec Subsidiary Agreement on Environmental Sustainability in Agriculture.

Spring-tine harrow (Rabewerk™)


Spring-tine harrow

The spring-tine harrow is used in muck soil to control weeds between crop rows. This harrow has six rows of 10 narrow flexible tines; they can be raised or lowered individually in order to cultivate specific areas. The raised tines may drop as a result of jolting when the harrow moves over uneven ground. However, they can be adjusted easily and crop damage is small since tines are kept raised above the crop row. This type of cultivator disturbs the soil to a depth of 2 to 5 cm. To ensure effective weed control, four cultivations are required early in the season at intervals of 5 to 7 days.

Rigid-tine harrow (Rabewerk™)

The rigid-tine harrow has rigid non-flexible tines and is used in mineral soil. As with the spring-tine harrow, each of the tines can either be raised or lowered depending on the


Rigid-tine harrow

surface to be cultivated. The harrowing depth ranges from 2 to 5 cm. For effective weed control, three successive cultivations must be made at intervals of 5 to 7 days.

Torsion weeder & spyders (Bezzerides™)


Torsion weeder & spyders

This cultivator consists of two units: spiked disks (Spyders) and steel rods (torsion weeder). This fairly aggressive weeder is suited to operate in both muck soil and mineral soil. Depending on the angle at which the disks are set, this weeder either pushes the soil away from the crop row or it ridges soil onto the row, uprooting any weeds it encounters. The torsion weeder consist of rigid steel rods, which are positioned on opposite sides of the crop row; they are slightly offset so

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they can work as close to the row as possible without injuring the crop plants. The teeth penetrate into the soil and uproot the weeds. Since the height and angle of each unit can be modified, the machine requires numerous adjustments. Furthermore, on account of the rounded shape of the disk attachments to the tool bar, this weeder exhibited a tendency to loose its adjustment. It works the soil to a depth of 5 to 10 cm. As a result of its aggressiveness, only a few cultivations (2 to 3) need to be made; hence, cultivation operations can be spaced farther apart during the season.

Rotary hoe (Yetter™)

Rotary hoe

The operating principle of the rotary hoe is simple: a series of rolling disks with spoon-shaped tips mounted on a common axle. This type of cultivator is used only in mineral soil. It offers several advantages, including rapid operating speed and preemergence blind harrowing. Although slight crop damage may be observed if cultivation is done right after crop emergence, the plants quickly recover. This type of equipment cannot be used with crops that are susceptible to damage. The rotary hoe breaks the soil crust, thus providing better aeration. It uproots sprouting weeds and works to a depth of 5 cm. Effective weed control is obtained following three cultivations with the rotary hoe.

Danish tines cultivator (Kongskilde™)

This is an aggressive cultivator that has S-shaped tines with triangular bladed tips. The tines dig deeply into

Danish tines cultivator

the soil, mixing and aerating it, as it uproots weeds. Danish tines have a working depth of about 10 cm. Because of its aggressiveness, fewer cultivations are required than with the other cultivators. It may be used as a follow-up to a rotary hoe.

Basket weeder (Buddingh™)

Basket weeder

This cultivator has two sets of baskets that each rotate on an axle; the first set of baskets has larger diameters and rotates slower than the second set. The baskets, which are manufactured in various widths, can be arranged along the axle according to the desired inter-row width to be cultivated. The adjustment is rapid since it merely entails selecting the baskets and positioning them on the axle. This type of weeder can be used in mineral soil or organic soil; its hoeing depth is 3 to 7 cm. Effective weed management requires making three to five cultivations during the season.

Rototiller

The rototiller is a very aggressive cultivator that is commonly used in organic soil; it cuts and buries weeds deeply. Since this machine is equipped with shields to protect the crop, it can operated near the row. It cultivates to a considerable depth, up

Rototiller

to a 10 cm. Only one or two cultivations are needed.

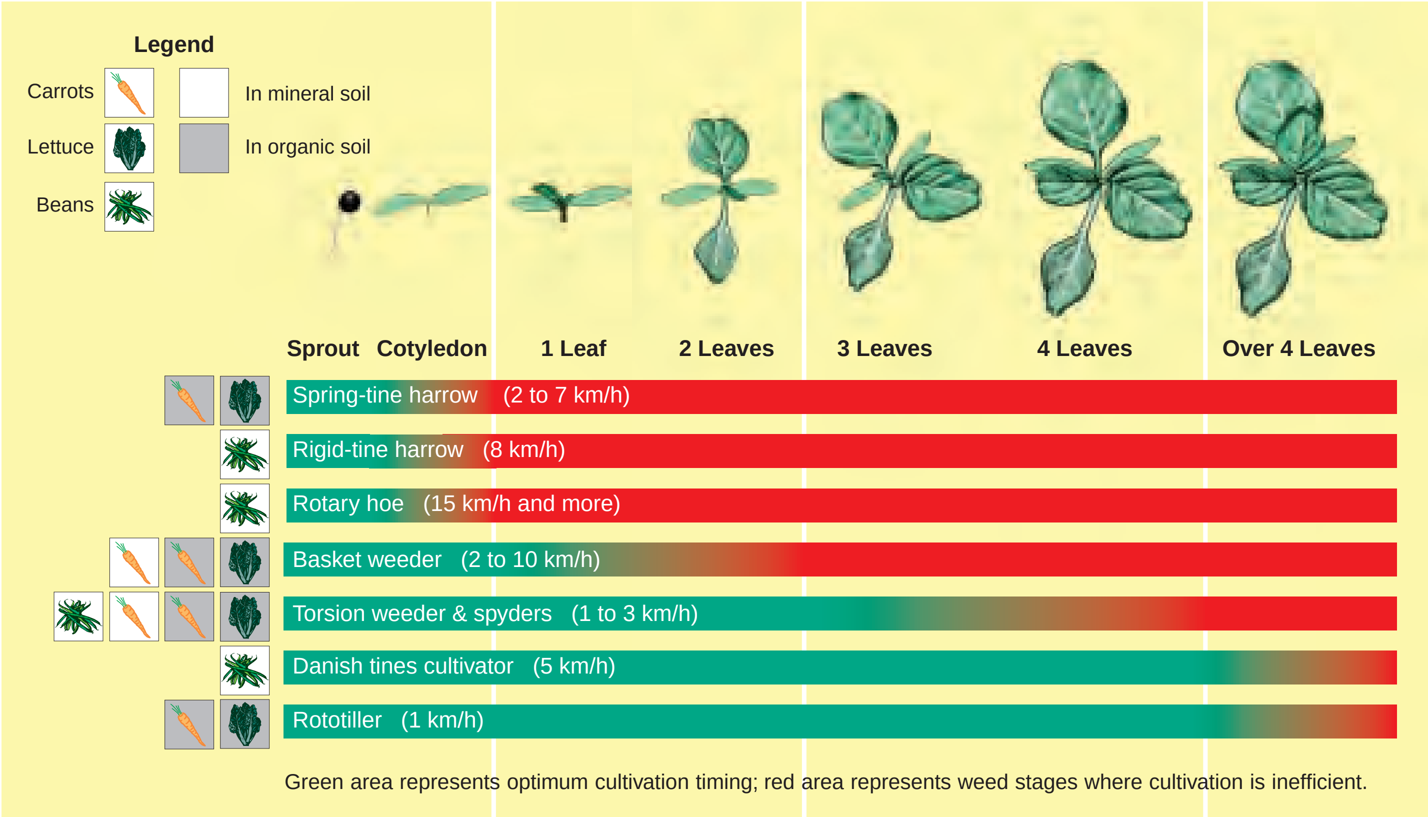
CHOOSING A CULTIVATOR

The goal of the research conducted by the Horticultural Research and Development Centre and McGill University was to test several types of mechanical cultivators in market vegetables to assess their weed control efficacy and their effects on crop plants. Vegetable crops selected for these trials represented market garden crops of economic importance to the fresh market and canning sectors.

Carrots

Carrots represent a crop which cannot tolerate root damage or displacement during its early growth stage. Mechanical cultivators may be used prior to crop emergence and until the crop rows have closed when cultivation is no longer feasible. To minimize damage, however, care must be taken to cultivate far enough from the row prior to carrot emergence and when they are small, up to 20 days after carrot emergence.

Four types of cultivators can be used in carrot production, depending on the stage of crop development and weed growth. In mineral and organic soils, a basket weeder or a torsion weeder & spyders can be employed. A spring-tine harrow or a rototiller can likewise be used in organic soil. The basket weeder (especially in organic soil) and the torsion weeder & spyders performed well in the field and produced good yields.



Cultivation timing and cultivator optimum operating speed for successful weed control in carrots, beans and lettuce.

Lettuce

Lettuce represent a crop whose leaves are susceptible to damage from mechanical cultivation. Cultivators may be used for weed control before the lettuce plants begin to form heads. However, to prevent damage, the cultivators must not be operated too close to the crop rows.

Four different types of cultivator are suited for weed control in lettuce: the spring-tine harrow, the torsion weeder & spyders, the basket weeder and the rototiller. The basket weeder and the torsion weeder & spyders offer good field performance and produce good yields.

Beans

Beans represent a crop whose flowers and pods are susceptible to mechanical damage. Special care must be taken if cultivation is done prior to the first trifoliate leaf stage, since beans are highly susceptible to damage at that time. Cultivators can be operated until the rows close up and flowering has begun.

Four types of cultivators can be used in beans. The torsion weeder & spyders gave the most consistent performance in terms of weeding efficacy. The rotary hoe is effective provided the weeds are sprouting but are not beyond the cotyledon stage. Rotary hoeing can be complemented by using the Danish tines cultivator between the crop rows later in the season. The Danish tines cultivator will destroy any weeds that have survived the cultivation with the rotary hoe, improving weed control considerably.

EFFECTS ON DISEASE INCIDENCE AND CROP YIELDS

Cultivators have virtually no effect on disease incidence (Trembley, 1997). It has been shown, however, that when disease incidence is high, there is a close correlation between the infection level and the amount of time required during the season to ensure full weed control. Consequently, the shorter the weed cultivation period and the greater the number of early-season cultivation, the lower the disease incidence can be expected. Disturbance of crop foliage associated with late-season cultivation can spread diseases or cause foliage damage, thereby promoting infection.

In general, mechanical cultivation provides yields and product quality equivalent to those obtained by conventional weed control methods and in some cases, may result in yield and quality similar to those obtained with manual weeding (Trembley, 1997). In beans, cultivators with a greater working depth appear to provide better results during dry growing seasons, whereas those working near the soil surface perform better when the growing season is wet. For carrots in organic soil, the research showed that the basket weeder produced the largest number of Canada No. 1 carrots. This weeder offers the advantage of shallow cultivation, preventing disturbances to root development. In lettuce crops, deeper cultivation with the torsion weeder & spyders appears to provide the best yields. Despite these differences, all the cultivators tested provide good yields, with no losses or deterioration in product quality.

ENSURING EFFECTIVE CULTIVATION

Regardless of the type of cultivator selected and the crop in which it is to be used, good cultivation does not only depend on the cultivator chosen but rather on the conditions in which it will be used. It is crucial to operate cultivators under optimal conditions in order to derive maximum benefit from them. The greater the weeder efficacy, the fewer the number of cultivations that will be needed during the season. Early and effective cultivations will make it possible to control weed infestations at the beginning of the season and possibly avoid the need for later cultivations, which may promote the spread of disease. This approach represents savings in time and money for growers.

Cultivators need to be adjusted so they will suppress weeds over the desired area without damaging the crop. The weed species present and their development stage will dictate the choice of the cultivator. Regardless of the intervention window for using a particular type of cultivator, the smaller the weeds are, the more effective the cultivation will be.

It is also important that the soil be dry both during and after cultivation. If the soil is too wet while cultivating, the weed control will not be adequate. The uprooted weeds are less likely to dry out and die. And if it rains following cultivation, the weeds may even re-root and start to grow again.

CONTROL STRATEGIES

The spring-tine harrow and the rigid-tine harrow can be used in market vegetable crops provided the weeds have not developed beyond the cotyledon stage. In contrast, a rotary hoe can be used only on large seeded crops such as beans; however, the intervention window is fairly narrow, from weed sprouting to cotyledon stage. Although the rototiller offers the greatest weed control efficacy, its very slow operating speed is a serious drawback. The basket weeder and the torsion weeder & spyders proved to be both practical and economical alternatives for the crops in which they were tested.

In carrots, herbicide use can be reduced by half by making band application of preemergence and postemergence herbicides on the row and by cultivating between the rows using a basket weeder in organic soil or a torsion weeder & spyders in mineral soil.

In lettuce, where the rototiller is used conventionnally, any cultivator that does not work the soil as deeply and that has a faster operating speed such as the basket weeder or the torsion weeder & spyders, can replace the rototiller.

Beans can be produced without herbicides by using a rotary hoe early in the season (2 cultivations), followed by a later cultivation with the Danish tines cultivator. To offset the plant losses when cultivating beans up to the first trifoliate leaf stage, it is recommended that the sowing rate be increased by 5 to 10%.

Mechanical cultivators represent a promising and cost-effective option for reducing or eliminating herbicide use in some market vegetable crops while maintaining yields and product quality.

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New Cultivation Tools for Mechanical Weed Control in Vegetables

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The recent trend toward restricting herbicide use has produced interest in alternative and integrated weed control strategies that include cultivation. As a result, newly developed implements are now available to vegetable growers, but the potential uses of these tools for numerous vegetable crops can be confusing. This publication describes some of these tools and their advantages and disadvantages, based on four years of research at Cornell University. It should be noted, however, that this is not a complete list; several other designs are available that were not tested in these trials.

Flex-tine harrows

Flex-tine harrows are used broadcast, both over and between the crop rows. They are most efficient when weeds are in the white-thread or cotyledon development stage. In direct-seeded crops, such as snap beans or sweet corn, flex-tine implements are used preemergence. Tines pass above the planted seed. Harrowing can be repeated postemergence for control of newly germinated weeds, but only when the crop is well-rooted. Cultivation intensity can be modified to minimize crop damage. Guide wheels and tine intensity regulate harrowing depth.

Advantages

- Tools are available in large widths (up to 40') and are operated at high speeds when used preemergence.
- Flex-tine implements are useful for a number of crops and row spacings with little or no equipment modifications.
- Tines that pass over the crop row can be lifted, allowing for aggressive between-row harrowing when the crop is sensitive to cultivation damage.
- Preemergence harrowing breaks crusted soils and may increase crop emergence rates.

Disadvantages

- Cultivation timing is critical; weeds with four or more leaves and emerged grasses at any stage are rarely controlled. Therefore, early-season flex-tine harrowing should be integrated with a more aggressive cultivator or with postemergence herbicides for control of escaped or newly germinated weeds.
- Research in transplanted broccoli, snap beans, and sweet corn has shown that flex-tine harrows can reduce crop stand and yield when used before the crop is wellrooted.

Implement Descriptions

Einbock flex-tine harrow

The Einbock harrow (Fig. 1) has floating beds of tines mounted on a tool bar. Cultivation on uneven ground or hillsides is possible with the floating bed system. Tines can be lifted above the crop row; however, tine intensity is modified on a bed-by-bed basis with a single adjustment.

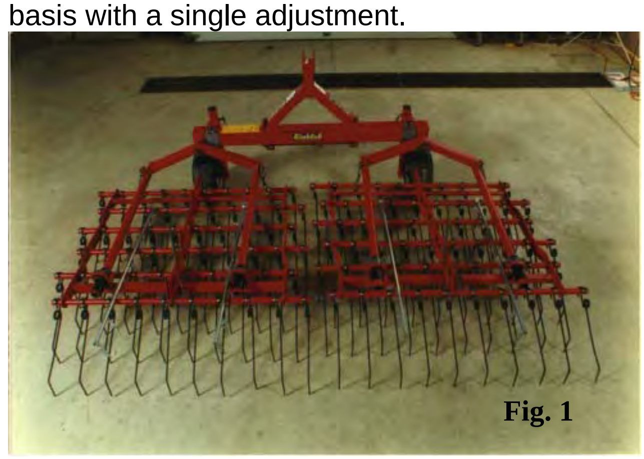

Fig. 1

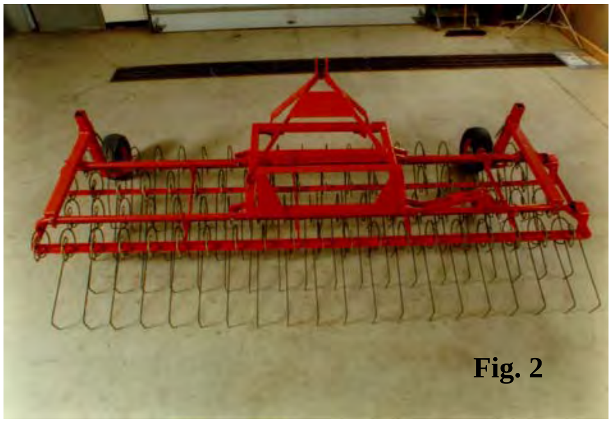

Fig. 2

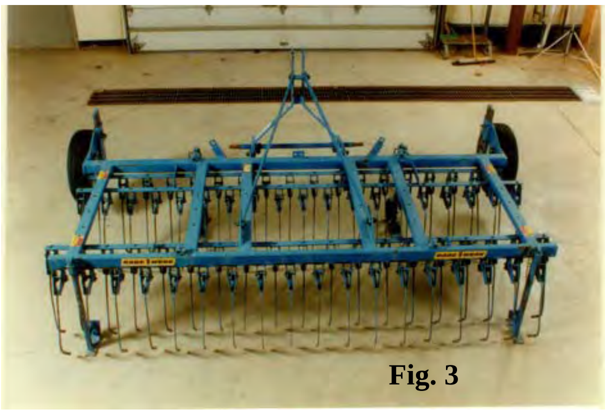

Fig. 3

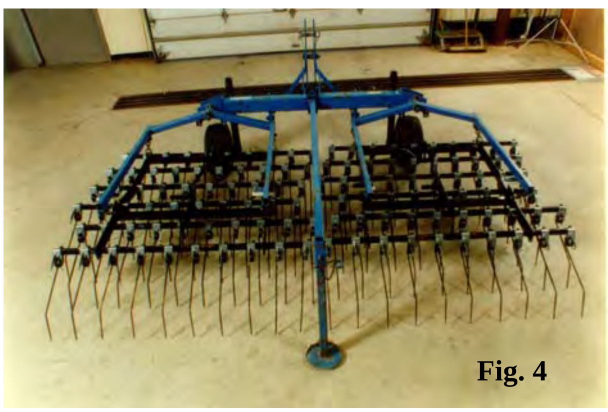

Fig. 4

Fig. 5

Lely flex-tine harrow

The Lely harrow (Fig. 2) is a lightweight tool with very flexible tines that vibrate to rip weeds from the soil. The implement's light weight can be a "cure or curse" -the harrow is easily maneuvered with a low-horsepower tractor, but its cultivation efficiency is reduced on hard-packed or crusted soils. Tine intensity is modified on a tine-by-tine basis.

Rabe Werk flex-tine harrows

Rabe Werk manufactures two harrows: one having flat tines (Fig. 3) and one with round tines (Fig. 4). The flat-tined harrow is very aggressive and effectively breaks crusted soils. Tines are modified individually in three intensities: high, low, and tines lifted above the crop rows. The round-tined implement is similar to the Einbock harrow and has floating beds of tines.

The Baertschi brush hoe

The brush hoe has PTO-driven plastic bristles that rotate on a horizontal plane, aggressively ripping weeds from the soil (Fig. 5). Shields, hung above the soil surface, protect the crop from .he rotating brushes but allow soil to move into the crop row. Because the tool is very aggressive and precise, an additional operator (on the rear seat) is required to steer the shields over the crop row. Cultivation depth is modified with guide wheels and the three-point hitch attachment. Several row spacings and brush configurations are available.

Advantages

- The aggressive nature of the brush hoe increases the length of time available for effective cultivation; weeds up to ten inches tall can be controlled.
- The implement is effective on slightly moist soils.
- Soil passing under the shields smothers weeds in the crop row.
- The dust layer that results from brushing delays new weed germinations. For example, in transplanted broccoli, a single pass of the brush hoe provided season-long weed control comparable to standard herbicides without reducing yields.

Disadvantages

- The brush hoe requires two operators.
- Wind erosion is possible with aggressive brushing on dry soils.
- Row spacing modifications are expensive and time consuming; therefore, all cultivated crops must have the same spacing.
- The initial implement purchase is costly.

The Buddingh finger weeder

The finger weeder is designed specifically for in-row weed control (Fig. 6). The tool has three pairs of ground-driven rotating fingers: two pairs in the front push soil and uprooted weeds away from the crop row; while the third pair pushes soil back into the row, covering weeds that were missed by the other fingers. The weeder is most effective when fingers pass very close to the crop row; therefore, precise cultivation and slow driving speeds are important. The finger weeder is most effective on small-acreage, high-value crops.

Advantages

- The weeder offers excellent in-row weed control.
- The finger weeder is a lightweight tool and can be mid-mounted on a small tractor.

Disadvantages

- The weeder must be used when weeds are small; therefore, timing is critical.
- Between-row control is poor. Finger weeders should be used in combination with an inter-row cultivator.
- Slow, precise cultivation is necessary to minimize crop damage.

Bezzerides torsion weeder

The torsion weeder is mounted on an existing inter-row cultivator for improved in-row weed control (Fig. 7). This simple tool has spring-loaded steel rods on each side of the crop row that undercut small weeds. The width of the uncultivated strip is easily adjusted for each crop and development stage.

Advantages

- The torsion weeder offers excellent in-row weed control.
- The simple design minimizes potential cultivator repairs.
- The torsion weeder is an economical addition to an existing cultivator.

Disadvantages

- Careful, accurate cultivation is important.

Integrated Management Strategies

The best weed control strategy often integrates several management strategies, which may include mechanical control. Two ways to reduce herbicide use while minimizing the risk of poor weed control and reduced yields are to combine cultivation with banded herbicides or with some of the new postemergence herbicides (e.g., Reflex and Basagran for small beans), used on an as-needed basis. Research in sweet corn, for example, has shown that yields were equivalent when a single cultivation was combined with Dual and Atrazine banded over the crop row and when the same herbicides were applied broadcast without cultivation, even in wet years. Results were similar in potato studies, where the combination of banded herbicides and a single hilling six weeks after planting produced yields equivalent to broadcast herbicides plus hilling.


Fig. 6

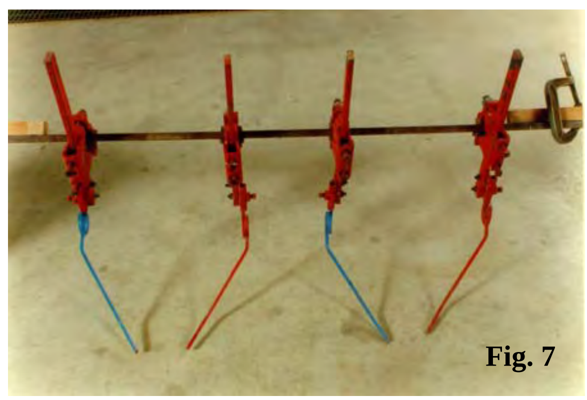
Fig. 7

Manufacturers

Brush hoe
Baertschi FOBRO 1715 Airpark Grand Haven, MI 49417 Phone: 616-847-0300 Fax: 616-842-1768

Finger weeder
Buddingh Weeder Co. 7015 Hammond Ave. Dutton, MI 49316 Phone: 616-698-8613

Torsion weeder
Bezzerides Brothers, Inc.
PO. Box 211
Orosi, CA 93647 Phone: 209-528-3011

Flex-tine harrows
Einbock:
Landaschinenbau GES. m.b.h. & Co. KG
A-4751 Dorf an der Pram
Austria
Phone: 43-7764-6466 Fax: 43-7764-65-3585

Canadian Distributor.
HWE-Agricultural Tech. Ltd.
Mr. Hans Evermann
B. E 1515 Cdn. Embrun, Ont. KOA 1W0 Phone/Fax: 613-443-3386

Rabe Werk:
Machinerie Agricole St. Cesaire Inc.
C.E 399, 650 Route 112 St. Cesaire, Qc JOL 1T0
Canada
Phone: 514-469-4081 Fax: 514-469-3659

Lely:
Lely Corporation
Box 1060, US 301 South Wilson, NC 27894 Phone: 919-291-7050 Fax: 919-291-6183

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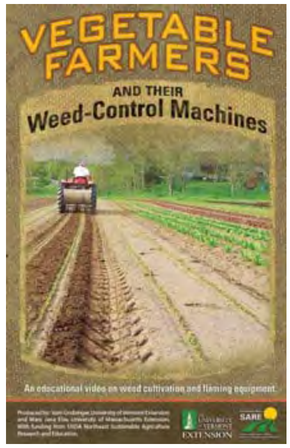

Vegetable Farmers and their Weed-Control Machines

A 75-minute educational video on weed cultivation and flaming equipment, featuring 9 farms in 3 northeastern states

Produced by:
Vern Grubinger, University of Vermont Extension
Mary Jane Else, University of Massachusetts Extension

With funding from:
Northeast Sustainable Agriculture Research and Education (SARE), USDA

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Video Content:

Bob Gray, Four Corners Farm, Newbury VT
*** Custom cultivator for plastic**
*** Rolling cultivator**
*** Finger weeder**

John Arena Jr., Arean Farms, Concord MA
*** Custom cultivator for plastic mulch edges**

Tim Taylor, Crossroad Farm, Fairlee VT
*** Basket weeder**
*** Rotary hoe**
*** Batwing shovels**
*** Field cultivator**

Chuck Armstrong, Fiddlehead Farm, Brownsville VT
*** Bezzerides tools**
*** Flex-tine weeder**

Lockwood 'Pooh' Sprague, Edgewater Farm, Plainfield NH
*** Flex-tine weeder**
*** Basket weeder**
*** Sweeps**

Gary Gemme, Harvest Farm, Whately MA
***Basket weeder**
*** Sweeps**

Tom Harlow, Kestrel Farm, Westminster VT
*** Custom flame weeder**
*** Stale seed bed roller**

Steve and Ray Mong, Applefield Farm, Stow MA
*** Bezzerides' tools**
*** Flame weeders**

Jake Guest, Killdeer Farm, Norwich VT
*** Backpack flame weeder**
*** Tractor-mounted flame weeder**

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UNIVERSITY OF VERMONT EXTENSION
CULTIVATING HEALTHY COMMUNITIES

RETURN TO VERMONT VEGETABLE AND BERRY PAGE

Cultivation Equipment

Websites for Specialty Tractor Cultivators (Univ. of Maine)

Tuff-bilt Tractor System (Southeastern Industrial Resources, Inc.)

Bezzerides Tools: Spyders; Spring Hoe Weeder; Torsion Weeder (Bezzerides)

Sweep/S-Time Cultivators (Market Farm Implements)

The Original Hillside Rolling Cultivator (Hillside Cultivator Company)

The Hillside Cultivator Model NH (Hillside Cultivator Company)

Lely Tine Weeder (Market Farm Implements)

Williams Tool System (Market Farm Implements)

Eco Weeders (Univerco)

Weed Ecology

University of Maine

Ben Costanzi

M.S. Student, Department of Plant, Soil and Environmental Sciences

Benjamin_Costanzi@umit.maine.edu

Subscribe to RSS feed

Finger Weeders

Nylon finger weeders, designed to targe intra-row weeds.

Torsion Weeders

Tractor Cultivators

The sites listed below feature tools that may be of interest to small- to mid-scale diversified vegetable producers, and are for informational purposes only, no endorsement is intended implied.

- ASABE Technical Information Library
  Searchable database, useful for finding information on machinery
- Bezzerides Brothers Inc.
  U.S. developer and manufacturers of innovative row-crop cultivation tools including Spyders and Torsion Weeders™
- Buddingh Weeder Co.
  U.S. inventor and manufacturer of the Basket Weeder
- Einböck GmbH & CoKG
- Steketee
  Dutch manufacturer
- ENVO-DAN aps
- Kress und Co.
  Finger weeders, hoes, basket weeders, and speciality tools for organic vegetable production.
- Jydeland Maskinfabrik A/S
- F. Poulsen Engineering
- Hatzenbichler
  Austrian manufacturer of tine weeders and precision inter-row hoes.
- Hillside Cultivator Co.
  Pennsylvania dealer of Hillside Cultivators, Tuff-Bilt Tractors (like an Allis G), and Eco Weeders.
- Lorenzo Mfg. Co. Inc.
  Source for clamps, shanks and other parts for fabricating or modifying a cultivator.
- Market Farm
  Pennsylvania dealer of the Williams Tool System, Lely tine harrows, Multivators and Real Wheel Hoes.
- Garford Farm Machinery
  Precision-guided hoes for row crops and cereals.
- FOBRO
  Precision hoes and brush hoes.
- Schmotzer
  German equipment manufacturer. We purchased a steering hoe for managing weeds in organic wheat (See "Current Research")
- Frato Machine Import
  Dutch dealer of torsion weeders and other tools.

May 7, 2010

Southeastern Industrial Resources, Inc.
P.O. Box 266 - 5700 Columbus City Road
Grant, AL 35747 - MAP

Phone (256) 728-3070
Fax (256) 728-3071
sir@scottsboro.org
Mon-Fri 7:00 - 3:30pm CST

Innovative... Affordable

Farmers and land owners are in a jam when it comes to those small acreage plots, too narrow or tough for their equipment. At last there's an affordable answer... The Tuff-bilt Tractor System.

Tuff-bilt Takes A Turn For the Better

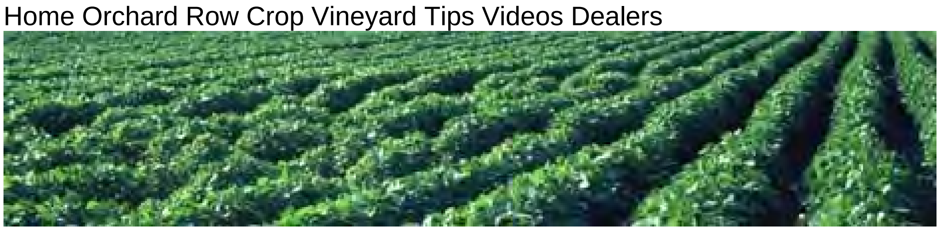
With a turning radius of just 84 inches, Tuff-Bilt turns circles around other tractors. Tuff-bilt takes the fight out of tough spots, cuts corners and time on the job.

The Perfect Answer For Whatever Field You Are In

With a range of 24 easy converting implements and accessories, Tuff-bilt can tackle almost any job. With our unique, patented hydraulic drive system, we can deliver 1,000 draw bar load pounds utilizing only a 16hp engine. Tuff-bilt comes standard equipped with two 3-point hitches (front and rear), hydraulically operated, with a lift capacity of over 700 pounds each.

Designed For The Worker And The Job

Built for driver comfort, easy turning and great visibility. The Tuff-bilt has a full twenty inch ground clearance and is easy on the pocketbook, maintenance cost, and on cost of operation. It uses only about a gallon of gas per hour.



Row Crop

- Spyder Weeders
- Torsion Weeders
- Spring Hoe Weeders
- Guide Wheels

Spyder Weeders™

Key Benefits

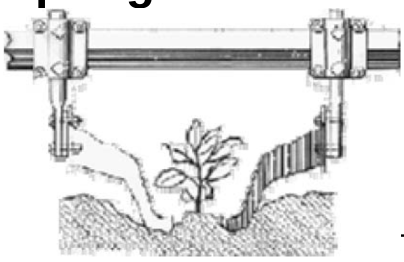
- REPLACES DISC HILLARS
- MULCHES & AERATES SOIL
- NO OBJECTIONABLE "SMOOTH SHOULDER" NEXT TO PLANTS
- CONSERVES MOISTURE
- MADE OF LONG WEARING SPECIAL STEEL
- ROTATES ON HEAVY-DUTY, BALL-BEARING HUBS

The Bezzerides™ Spyder Weeder™ is an ideal tool to use ahead of the Torsion Weeder™, Spring Hoe Weeder™. They do not leave a smooth ridge or shoulder that dries out. The staggered teeth of the Spyder Weeder™ mulches the soil in an uneven pattern which is then easily loosened by the Torsion Weeder™ or Spring Hoe Weeder™. Unlike some tools, the Spyder Weeder™ helps reduce the amount of clods formed during cultivation. If desired, with a simple adjustment, the Spyder Weeder™ can be angled to move the soil towards the plant row. All of these advantages can help contribute to better harvesting conditions in sugar beets, cotton and many other row crops. Spyder Weeders™ are built for long wear and rotate on heavy-duty, ball-bearing hubs. They fill an important gap in today's modern farm tillage.

OPERATING INSTRUCTIONS

Install Spyder Weeders™ on each side of the plant row. The front of the Spyder Weeder™ should be closest to the row with the bent teeth toward the plant and pointing down at the rear. When the curved teeth point up at the rear, their action is more severe and will be more prone to plugging. They should operate at approximately a 30 degree angle to the row and at the desired depth.

Spring Hoe Weeder™



The Bezzerides™ Spring Hoe Weeders'™ "magical action" disturbs and mulches the soil around and **between** the plants, uprooting and killing noxious weeds. The rapidly oscillating spring blades work just below the surface which provides an adequate "safety factor" in preventing plant damage. The effect is amazing... you travel at a fast rate of speed and the Spring Hoe Weeder™ does a perfect job of cultivating and weeding around and **between** the plants.
Spring Hoe Weeders™ give you an entirely new system of plant cultivation. You get the weeds while they are small with periodic repeats you can keep manual labor to a minimum. The working tips of the Weeder blades travel beneath the soil around the base of the plants. This uproots the weeds and aerates and mulches the earth. The plants themselves are not disturbed because their root systems are firmly established.

> Spring Hoe Weeder™ units, for each row, consist of two right and two left, scientifically-shaped, special spring steel blades and two mounting brackets with slotted adjustment holes. Adapter brackets for use with spring trip shanks are available if requested. The two loft and right blades are set to work opposite each other at 45 degree angles to the row. As the tractor travels forward, the spring blades oscillate vigorously beneath the surface and it is this compression and vibration that that disturbs the soil and efficiently mulches and weeds at the same time.
>
> In harder soil the blades are set closer together because the extra resistance of the heavy soil tends to spread the blades apart. Many users double-up the blades (eight blades to a row) in extremely tough conditions. When working in light soil the blades may be set farther apart and still efficiently cultivate the soil.

Spring Hoe Weeders™ are available in two models. The first model is 2030L(left) and 2031R(right) (recommended for single row cultivation). The blades are 16.5 inches long and has a working tip area of 6 inches. This model should be set for a 13.5 inch spread, which allows the user to mount the unit with a greater distance from the plant row and work

The second model is 2040L(left) and 2041R(right). The blades are 16.25 inches long with a 4 inch working tip area. This model is used primarily in bottom furrow and double-row cultivation. Many double-row crops planted on beds have a crown between the two rows of plants. The second model should be set for an 11.5 inches spread, which enable the user to cultivate close without moving the dirt in the crown toward the plants.

Torsion Weeder™

The best time to eliminate weeds in row crop is while they are young, before they can establish a good root system. Having tools for complete row crop cultivation, we here at Bezzerides™ Brothers have found a need for special tools to be used on small, tender plants. The Bezzerides™ Torsion Weeders™ were designed for just this purpose -- to work in and around the plant row, eliminating as many weeds as possible without moving a lot of soil.

Torsion Weeders™ are made of high quality spring steel and are designed to mounting in either a Torsion Weeder™ standard , or are easily adapted to our Spring Hoe Weeder™ bracket. Both mounting methods allow full adjustment so you can get as delicate or severe as conditions will permit.

Installing Spyder Weeders™ and Torsion Weeders™

Remove discs. Install the hub to the side of the Spyder Weeder™, in which, the bent teeth point. Once the hub and Spyder Weeder™ are installed on the Standard the bent teeth should point away from the standard and toward the plant row with the rear teeth pointing down. Offset the left and right sides by placing one clamp to the front of the tool bar and one clamp to the rear. This allows
for better adjustment. Also, if there is debris in the row this will allow it to be pulled out of the row without dragging it over the plants. You can adjust them to the desired depth and as closeness that your conditions allow.
Install the Torsion Weeder™ brackets on the standards and adjust the Torsion Weeders™ to the desired depth and closeness. You can determine how severe to adjust them simply by trial -- all you want to do is break up the soil around and between the plants at a slight depth. The speed of travel will have an impact on this. You will be amazed at the results. The earlier you can get the weeds, the more effective you cultivation will be.
On later cultivation you can set the Spyder Weeders™ further from the row in front and closer in the rear to break up the soil between the plants. Then as the Torsion Weeders™ come through the weeds will be obliterated.

Cultivation Tips

Spyder Weeders™ in front and Spring HoeWeeders™ in the rear

This is an ideal setup for cultivating after an irrigation where th plants have grown and you have a new crop of weeds growing.
Note: With the angle of the Spyder Weeders™ set wider in front and closer in rear it compresses and fractures the soil. With the Spyder Weeders™ teeth at an angle toward the row it has a lifting action. With the Spring Hoe Weeders™ in the rear you are able to work the soil in between and around the plants practically eliminating all of the weeds.

Sweep/S-Tine Cultivators

Online Catalog
Tillage
Rock Pickers
Bed Shapers
Mulch Layers
Mulch Lifters
Straw Mulching
Transplanters
Seeders
Cultivators
Fertilizer Spreaders and Attachments
Sprayers
Harvest Equipment
Packing House
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Sweep and **S-Tine Cultivators** are between-row cultivators that have sweeps of various sizes mounted on a toolbar so they can be adjusted to cultivate between narrow or wide rows. The sweeps are mounted on spring shanks that will relieve and reset if a hard object is struck. Gauge wheels provide accurate depth control, especially on S-Tine Cultivators that have gangs of sweeps that float independently on their own depth gauge wheel. They can cultivate rows from about 16" and up. Optional equipment includes in-row cultivating tools, crop shields, fertilizer attachments, and guidance systems for cultivating to within 1" of the row.

Sweep Cultivator

1 Row	$1,570.00
2 Row	$1,464.00
3 Row	$1,358.00
4 Row	$1,252.00

S-Tine Cultivator

1 Row	$930.00
2 Row	$1,275.00
3 Row	$1,470.00
4 Row	$1,665.00

Original

The Original Hillside Cultivator

The Hillside Cultivator is a versatile tool for many uses. Its unique feature is its ability to move soil uphill as the tractor is moving either direction on the side of the hill.

► Rolling cultivators cut and tear weeds from the soil.

► Cultivators have a light ridging effect toward the row but are not as damaging to soil structure as a rototiller.

► The angle at which the cultivator units operate is hydraulically adjusted from the tractor seat. This is to avoid covering plants from the upper side of the row.

► This type of cultivator works in a no-till situation moving through moderate plant debris without clogging.

► Two heavy s-tines loosen soil behind the tractor wheels.

► Many adjustments allow for cultivating narrow rows and those up to a width of 48".

► The rolling cultivators do a good job of covering small weeds along the edges of plastic and maintaining soil on the edge of raised beds.

For more information call (717)626-6194 or click on the envelope to e-mail sales@shenkberryfarm.com

Model NH

The Hillside Cultivator Model NH.

Manually adjusted Toolbar

This is a fully adjustable cultivator which removes weeds through the very effective work of rolling cultivator gangs and coil tines.

The ground driven rolling cultivators uproot all the weeds in their path and can be used where plant debris is present in the field.

These adjustments can be made to the rolling cultivators. The mounting plate allows for lateral adjustment and the angling of the cultivator gang. The pitch of the gangs is also adjustable.

The clamps which hold the cultivators to the tool bar may be positioned to a variety of locations depending on the size of the crop to be cultivated or the width of the bed.

The rolling cultivators have a ridging effect toward the plant row.

These cultivators have been found very useful for cultivating strawberries, potatoes, vegetables, and nursery plants grown on raised beds or ridges.

For more information call (717)626-6194 or click on the envelope to e-mail sales@shenkberryfarm.com

Lely Weeder

The **Lely Weeder** is a Blind Cultivator and can be adjusted to be used as a between row cultivator as well. The 6mm tines are set 1 1/2" apart across the entire width of the bed and float independently. It can be used as a blind cultivator with all the tines down until the crop is 3" - 8" tall, then the tines over the row can be raised and the cultivator used as a between row cultivator. The depth of each tine can be adjusted. Optional gauge wheels help control the depth of the cultivator and act as parking stands. It can be used in clay or sandy soils and works around rocks better than other blind cultivators. Imported from Holland.

7'	$2,300.00
10'	$2,845.00
14'	$3,365.00
19'	$4,555.00
Gauge Wheels	$650.00

Williams Tool System

Online Catalog
Tillage
Rock Pickers
Bed Shapers
Mulch Layers
Mulch Lifters
Straw Mulching
Transplanters
Seeders
Cultivators
Fertilizer Spreaders and Attachments
Sprayers
Harvest Equipment
Packing House
New Items
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Our Best Cultivator:

The Williams Tool System features a 40", 50" or 60" spring tine rake with a front and rear toolbar to mount optional cultivator tools, gauge wheels and track sweeps to custom cultivate any crop in any soil type accurately. The Tool System is the only precision bed cultivator that gives complete cultivation across the bed by using the right tool for the job. It can work in any soil type, cultivate almost any row spacing and adjusts quickly. This all purpose cultivator can take the place of all the other cultivators on your farm.

The Tool System cultivates blind before and after emergence in the row and between the row on fast germinating crops like corn, peas, beans, cucumbers, squash and pumpkins. You simply set all of the tines down and rake the bed. It can also be used as a between row cultivator in slow germinating crops like direct seeded carrots, lettuce, cabbage and broccoli by simply lifting the tines out of the in-row area as desired. The rake alone will not remove perennial weeds and grasses between the rows. For these weeds, the optional sweeps or side knives are used because the combination of a sweep followed by the rake works best. The sweep cuts the root and the rake lifts the weed out to the surface where it will dry out and perish.

The side knives can also be used to hill transplanted crops and fast germinating seeds once they are tall enough for hilling by positioning the wing tip end of the side knife toward the row to maintain in-row weed control. The optional track sweeps are used to cultivate the wheel tracks and the optional gauge wheels are used to control the depth of the cultivation tools when a guidance system is not used. Several fertilizer attachments are also optional. The Tool System can cultivate as close as 1" to the row with an optional guidance system.

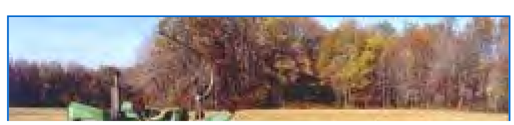
Williams Tool System

40" Rake, Cat I	$1,680.00
50" Rake, Cat I	$1,800.00
60" Rake, Cat I	$1,920.00
Cat II Hitch	$60.00
Gauge Wheels, pair	$210.00
Guide Wheels, pair	$684.00
Guide Cones, pair	$486.00
Track Sweeps, pair	$310.00
Side Knives, 7" pair	$118.00
Pumpkin Knives, pair	$132.00
Strawberry Discs, pair	$448.00

All Accessories Priced With Clamps

When cultivating on flat ground, the optional guide wheels are used for guidance. The guide wheels are mounted on the planter first to make one or two guide furrows inside of the rear tractor tires. At cultivation, sway is put into the hitch by loosening the sway chains or raising the sway blocks so the guide wheels stay in the guide furrows while the tractor is allowed to steer off of the row. At cultivation, sway is put into the hitch by loosening the sway chains or raising the sway blocks so the guide wheels stay in the guide furrows while the tractor is allowed to steer off of the row. With guidance, the cultivator tools can be adjusted to within 1" of the row because you do not have to allow for the off steering of the tractor. It can cultivate closer to the row than a cultivator guidance tractor with belly mounted tools because it removes human error in steering the cultivator. The tractor just pulls the cultivator and is not used to guide it.

When cultivating on raised beds , the optional guide cone bed huggers are used for guidance. They are used at planting first to



guide the planter so the rows are planted
parallel to the shoulders of the raised bed. Then the guide cones are mounted on the cultivator and adjusted to hug the shoulders of the raised bed. Sway is put into the hitch so the planter and cultivator follow the shoulders of the raised bed and are not steered by the tractor. This allows the cultivator tools to accurately follow the rows planted on the bed, while the tractor is allowed to off steer.

With the guidance system you can **machine cultivate hand plantings** for precision weed control. With the guidance system mounted on the cultivator, rake tines are lowered to mark where the rows are to be hand planted while the guide wheels create the guide furrows. Guide cones are used when planting on raised beds. Next the plants, seeds or tubers are hand planted on the marked rows, then the guided cultivator tools can be adjusted to cultivate close to the rows. This provides ideal weed control for small scale growers and market gardeners with a minimum amount of machinery.

It is the **best cultivator for strawberries** because it can cultivate in the row and between the row during the first year of growth, and can be fitted with disc gangs for strawberry renovation, and cultivation during the 2nd year.

It is the **best cultivator for potatoes** because it can hill potatoes with the optional 16" hilling discs and then continue to weed the hills with the rake until the vines are about 18" long.

It is the **best cultivator for pumpkins** and other vine crops because it can rake in the row until the plants are about 4" tall, then be fitted with long side knives that hill the row even after the crop has vined 12". The 13" long side knives sweep under the vine and hill the stem, giving the best weed control possible.

It is the **best cultivator for direct seeded lettuce and carrots** because it can cultivate closer to the row than any other cultivator by using the guidance system.

It is the **best cultivator for fast germinating crops** because it can cultivate blind before and after emergence with all of the rake tines down, then be adjusted to cultivate between the rows with the side knives and rake tines and hill the crop lightly by placing the wing tip of the side knife toward the row to maintain in-row weed control as the crop gets taller for complete vegetable bed cultivation.

It is the **best cultivator for market gardeners** because it can be adjusted quickly to cultivate any crop in almost any row spacing in any soil type and can cultivate hand plantings accurately by using the guidance system

Our Best Cultivator In Stock!!! - Coming soon on VHS Video!

Eco Weeder

Hillside Cultivator is a licensed dealer for the Eco Weeder. This is an excellent cultivating tool for removing the weeds between the plants in a row. The Eco Weeder is a 3-point hitch, power take-off (PTO) driven tractor-mounted cultivator.

The PTO vertical tines remove weeds from between and around the plants. An operator rides on the seat and uses the handles to control the power-driven tines.

95% of the weeds around the plants can be removed with this implement without the need for hoes or hand-weeding.

We use this successfully at Shenk's Berry Farm for the removal of weeds around strawberry plants.

For more information, see:

http://www.univerco.com/nouveausite/weeder.php

BioHerbicides

Comparison of BioHerbicides (UD Summary)

Green Match EX (Marrone)

Weed Zap (JH Biotech)

Weed Pharm (Pharm Solutions)

Burnout II (St. Gabriel Labs)

Natural Wet (SaferGro)

Nu-Film-P (Miller)

Corn Gluten Meal (ISU)

Greenhouse Screening Corn Gluten Meal (HortScience)

Summary of Bioherbicides based on websites and labels (October 2010)

Herbicide	OMRI*	Additives**	Veggies***	Non-crop
	Label specifies			
Burnout II	No	No	No	Yes
EcoEXEMPT	No	Yes1	No	No
Matratec	Yes	Yes2	Yes	Yes
Scythe	No	No	Yes	Yes
Avenger	Yes	No	No	No
Weed Pharm* (20% aa)	No	No	No	Yes
Weed Pharm* (8% aa)	No	No	No	Yes
Alldown	No	No	Yes	Yes
GreenMatch EX	Yes	Yes1	Yes	Yes
WeedZap	Yes	Yes3	No	No

*OMRI approved
**Are additives required
1= only mentions adjuvant
2= mentions adjuvant and acidifying agent
3= mentions yucca extract
***Labeled for use in vegetables

Herbicide	G/A*	low rate	high rate	$$/gal		Cost ($/A) Low	High
Burnout II	35	33 %	50 %	25.98	2	300.07	974.25
EcoEXEMPT	50 +	15 %	20 %	66.90	1	501.75	1338.00
Matratec	25	5 %	10 %	103.60	3	129.50	1036.00
Scythe	75 +	3 %	10 %	76.90	1	173.03	769.00
Avenger	50	15 %	25 %	59.95	3	449.63	1498.75
Weed Pharm** (20% a	50	100 %	100 %	25.00	4	1250.00	2500.00
Weed Pharm** (8% aa	50	33 %	33 %	25.00	4	412.50	825.00
Alldown	50 +	25 %	33 %	12.81	2	160.15	422.80
GreenMatch EX	35	7 %	15 %	33.20	2	81.34	498.00
WeedZap	50 +	3 %	3 %	84.00	2	126.00	126.00
Natural Wet (saponin,	25 +	0.125 %	0.125 %	35.98	5	1.12	4.50
Nu Film P	25 +	4 oz/A	16 oz/A				
Aim	15	1 fl oz/A	2 floz/A	221.00 (qt)		6.90	13.79
Crop Oil Concentrate		1 qt/A	1 qt/A	12.00		3.00	3.00
Organic Preen (100% corn glute		870 lbs/A	1740 lbs/A	$15/lb	6	2610.00	5226.00
Corn Gluten Weed Blocker		870 lbs/A	1740 lbs/A	$11/lb	4	1367.14	2737.43

*Gallons per acre (G/A) based on label recommendations
**+ contains food-grade vinegar at 200 grain (20% acetic acid)
1= Biocontrol Network (www.biconet.com)
2= Peaceful Valley Farm Supply, (www.groworganic.com)
3= Johnny's Seeds (www.johnnyseeds.com)
4= Pharm Solutions (www.pharmsolutions.com)
5= Environmental Green Products (www.environmentalgreenproducts.com)
6= Home Depot

GreenMatch EX Burndown Herbicide

INTRODUCING GreenMatch®EX
Burndown Weed Control For Use on Organic CROPS

GreenMatch®EX offers organic growers an EFFECTIVE alternative to costly hand weeding, flaming, mowing and cultivation in their battle to keep crops free of weeds. GreenMatch EX is an effective and economical burndown herbicide that is fast-acting, easy to apply and active on a broad spectrum of weeds.

GreenMatch EX is non-selective, and controls most annual and perennial weeds, both grasses and broadleaves. It is a fast-acting, post-emergence herbicide for use on weeds that already exist.

More Information

- Label
- MSDS
- Brochure
- Field Data
- Sales/Distribution
- Comments
- Organic Certificates

The active ingredient in GreenMatch EX is Lemongrass Oil, a powerful, herbicidal, essential oil that strips away the waxy cuticle from weeds' leaves, causing fast wilting (necrosis), dehydration and death. Lemongrass oil provides a longer lasting burndown than other essential oils, and is further strengthened by other natural oils and surfactants in the GreenMatch EX formula.

"EX" stands for Exempt
All components in the product are natural, food-grade, organic ingredients, qualifying GreenMatch EX as exempt from registration under FIFRA (the Federal Insecticide, Fungicide and Rodenticide Act).

ORGANIC
GreenMatch EX meets the requirements of the NOP Rule for use in organic agriculture. In addition to NOP compliance, GreenMatch EX is listed by the Organic Materials Review Institute (OMRI). It is also a registered material in the Washington State Department of Agriculture's Organic Food Program (WSDA).

CROP USE
GreenMatch EX may be used on organic cropland to provide excellent burndown control of most grasses and broadleaf weeds. Its concentrated emulsion formula is easily mixed and sprayed on targeted weeds. Like all non-selective, burndown materials, care must be taken to avoid contact with crops or other desirable vegetation, as all green tissue may be damaged. Also, as with other burndown products, coverage is very important. There is no re-entry interval required after spraying GreenMatch EX.

Non Crop Use
GreenMatch EX also offers an excellent alternative to chemical herbicides for non-crop uses. It can be applied in environmentally sensitive areas, for landscaping, at schools, parks, recreation facilities or any area with proximity to people or pets. Use it on cracks, edges, around fence posts, tree wells, etc. to kill most weeds. Do not spray on lawns as it is non-selective and will kill grass.

ENVIRONMENTAL STEWARDSHIP
GreenMatch EX is non-toxic and highly biodegradable. It contains only food grade ingredients that have low impact on the environment, non target organisms and workers.

DISTRIBUTION
GreenMatch EX is available in 5 gallon pails.
Call your local agricultural input supplier to purchase GreenMatch EX, or contact Marrone Bio Innovations by using our email form or calling 1-877-664-4476

WEED ZAP™

OMRI Listed
Organic Materials Review Institute

JHBiotech
Biotechnologies for Safer Agriculture

ONE APPLICATION

Before | After

Benefits of Weed Zap:

Weed Zap is an all natural non-selective herbicide. Weed Zap "zaps" small broad leaf and grassy weeds. It's natural ingredients will eliminate plants that are six inches in height or less. Weed Zap is a broad spectrum herbicide that is suitable for organic production.

Weed Zap is 100% biodegradable, which makes it an environmentally smart product to use around houses, schools, parks, playgrounds or anywhere people and pets are present.

Weed Zap is a natural herbicide, it's ingredients are listed as food grade materials. For this reason, Weed Zap is exempt from EPA registration - reducing paper work and worry.

- Pleasant Clove Scent
- Easy to Mix and Apply
- Kills Most Weeds in 12 Hours
- Suitable for Organic Production
- Kills Most Broadleaf Weeds and Grasses

Weed Zap will not damage mature and non-green, woody plant parts and has both contact and physical modes of action.

JH Biotech, Inc. Phone: (805) 650-8933 Fax: (805) 650-8942 E-mail: biotech@jhbiotech.com http://www.jhbiotech.com

MODE OF ACTION:

Weed Zap binds to the surface of the plant, where it translocates into the cells of the plant. Weed Zap's ingredients begin to destroy the plant cell structure through a burn down process. Results can be seen in as little as six hours after application. Weed Zap works best in non-shaded open areas, on herbatious weeds 6" or less in height.

Contact your local JH Biotech distributor for more information.

IS EFECTIVE ON:

- Netseed Lambsquarter
- Common Mallow
- Bristly Oxtounge
- Prostrate Pigweed
- Canary Grass
- Rag Weed
- Starthistle
- Prickly Lettuce
- Common Cocklebur
- Chick Weed
- AND MANY MORE
- Sowthistle
- Leafy Spurge
- Bermuda Grass
- Hairy Fleabane
- Pig Weed
- Bursage
- Knapweed
- Dandelion
- Wild Mustard
- Wood Sorrel

JH Biotech, Inc.
4951 Olivas Park Drive
Ventura, California 93003 USA

PHARM SOLUTIONS

WEED PHARM

www.pharmsolutions.com

FAST ACTING WEED & GRASS KILLER

Ready-to-use

A FOOD GRADE ORGANIC ACID

For Non-Selective Control of Herbaceous Broadleaf Weeds and Weed Grasses on Residential, Non-Crop, Right-of-Way, and Industrial Land Sites

35 Fl. Oz.

KEEP OUT OF REACH OF CHILDREN

DANGER - PELIGRO

Si usted no etiquets, busque a alguien para que se la explique a usted en detalle. (If you do not understand the label, find someone to explain it to you in detail.)

EPA Registration No. 81936-1-81935
EPA Establishment No. 81936-WA-001

Pharm Solutions Inc.
2023 E. Sims Way.
Suite #358
Port Townsend, WA 98368

Active Ingredients by wt.

Acetic Acid	20.0%*
Other ingredients . . .	80.0%
TOTAL	100.0%

*Equivalent to 200 grain vinegar by titration

First Aid

If in Eyes

Hold eyelids open and flush with a steady, gentle stream of water for 15-20 min. Remove contact lenses, if present, after first 5 min., then continue rinsing eye.

If on Skin or Clothing

Take off contaminated clothing. Rinse skin immediately with plenty of water for 15-20 min. Call poison control center or doctor for further treatment

If Swallowed

Call poison control center or doctor immediately for treatment advice. Have person sip a glass of water if able to swallow. Do not induce

First Aid cont.

vomiting unless told to do so by poison control center or doctor. Do not give anything by mouth to an unconscious person.

If Inhaled

Move person to fresh air. If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. Call poison control center or doctor for further

NOTE TO PHYSICIAN: Probable mucosal damage may contra-indicate the use of gastric lavage.

Have product container or label with you when calling poison control center or doctor, or going for treatment. You may also contact 1-800-858-7378 for emergency medical treatment.

See label inside panel for additional precautionary statements.

PRECAUTIONARY STATEMENTS

Hazards to Humans and Domestic Animals:

DANGER: Corrosive - causes irreversible eye damage. Wear goggles or face shield when handling. Harmful if absorbed through skin. Harmful if swallowed. Do not get in eyes, on skin, or on clothing. In case of contact, immediately flush eyes or skin with plenty of water. Get medical attention if irritation persists. Wash thoroughly with soap and water after handling. Wear personal protection equipment when handling and/or applying.

PERSONAL PROTECTION EQUIPMENT (PPE): Applicators and other handlers must wear appropriate protective eyewear, such as or face shield or goggles and face mask (with MSHA/NIOSH approval number prefix such as N-95, R-95, or P-95), long sleeved shirt and long pants, waterproof gloves and shoes plus socks.

USER SAFETY REQUIREMENTS: Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions exist for PPE, use detergent and hot water. Keep and wash PPE separately from other laundry.

USER SAFETY RECOMMENDATIONS: Users should:

- Wash hands before eating, drinking, chewing gum, using tobacco or using the toilet.
- Remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.
- Remove PPE immediately after handling this product. Wash the outside of gloves before removing. As soon as possible, wash thoroughly and change into clean clothing.

Environmental Hazards: Do not apply directly to water, or to areas where surface water is present or to intertidal areas below the mean high water mark. Do not contaminate water when disposing of equipment wash water or rinsate. Do not apply to roosting or nesting birds, or to flowering plants during times of day when bees are actively foraging.

OTHER PRECAUTIONS: Avoid application to reactive metals such as aluminum, tin, iron or items such as fencing or lawn furniture in order to prevent staining, mottling, or otherwise interfering with finished metal surfaces. In case of contact, rinse the sprayed surfaces with water.

DIRECTIONS FOR USE: It is a violation of federal law to use this product in a manner inconsistent with its labeling. Do not apply this product in a way that will contact workers or other persons, either directly or through drift. Only protected handlers may be in the area during application. For any requirements specific to your State or Tribe, consult the State or Tribal agency responsible for pesticide regulation.
Keep unprotected persons out of treated area until spray residues have dried.

WEED PHARM is a fast-acting, non-selective contact killer containing an organic acid that is non-residual in soil. Foliar contact results in rapid desiccation and control of annual weeds and grasses, and top growth reduction of herbaceous perennial weeds and grasses (see tables below). Re treatment may be required for control of established perennial weeds. PROTECT ORNAMENTALS FROM SPRAY DRIFT.

EARLY SEASON ANNUAL WEED CONTROL: Apply undiluted product when weeds are small (3 to 5 leaf stage) and actively growing.
Spray Weed Pharm on unwanted vegetation to point of wetness. For best results spray in full sunshine at temperatures above 50 degrees Fahrenheit. Dilution of product will reduce effectiveness. Avoid spraying landscape plants, ornamentals and other desirable foliage.

TYPICAL WEEDS CONTROLLED - ANNUAL BROADLEAF WEEDS: **Black Medic, Chickweed**, Cinquefoil (rough), Common groundsel, Hairy Nightshade, Lamb's Quarters, Mustard spp., Oxalis spp., Pigweed spp., Ragweed spp.., Shepards Purse, Smart Weed (Lady's Thumb), Velvet Leaf

TYPICAL WEEDS CONTROLLED (Continued) - PERENNIAL BROADLEAF WEEDS*:* Cinquefoil (silvery), Dandelion, Ground Ivy, Plantain spp.,Toadflax, Tufted Vetch, Wild Carrot. **ANNUAL GRASSES*:*** Crabgrass, Foxtail spp, Italian Ryegrass, Poa annua. **PERENNIAL GRASSES*:*** Bluegrass, Quackgrass, Witches Grass

Weed Pharm Weed & Grass Killer is a food-grade, 20.0% Acetic Acid labeled for use as a horticultural vinegar for residential and non-agricultural uses at all sites indicated below!
Recommended for the control of herbaceous broadleaf and grassy weeds and unwanted grasses around buildings, storage areas, fence rows and driveways; in home lawns and landscaped areas, private association ornamental gardens, golf courses, school play fields, municipal, state and federal parks and recreation areas, non-cropland driveways, patios, sidewalks and bike/hike trails, kennels, dog runs, and other animal enclosures;
Interstate Freeways/Highways, Federal and State Highways and City/County roads and walk ways, railroad rights-of-way, tank farms, power stations and easements, and other rights-of way, industrial sites, and vacant lots.
Suitable to keep down weeds on all botanical and private association ornamental gardens, kennels, dog runs, and other animal enclosures and on Interstate Freeways/Highways, Federal and State Highways and City/County roads and walk ways.

FOR SPOT TREATMENT: Direct spray to thoroughly wet undesirable weed foliage. Re-treatment of perennial weed growth may be required for control.

FOR CONTROL OF LARGER ANNUALS AND BURN DOWN OF PERENNIAL WEED GROWTH: Larger annual weeds and perennials are more difficult to control and may require re treatment. Treat initially as recommended above and repeat if new growth of leaves appears. Thorough coverage of all weed foliage is necessary to achieve desirable control.

TIMING OF APPLICATIONS: Best results are achieved from applications to actively growing young weeds. Weeds that are mature, dormant or hardened due to moisture stress are more tolerant of herbicide treatments. For best results spray in full sunshine at temperatures above 50°F. Only contacted vegetation will be affected.

DO NOT APPLY THIS PRODUCT THROUGH ANY TYPE OF IRRIGATION SYSTEM.

NOTE: ALL CONTACTED VEGETATION WILL BE AFFECTED. AVOID CONTACT WITH DESIRABLE PLANTS. OVER SPRAY OR DRIFT WILL INJURE OR KILL CONTACTED VEGETATION.
STORAGE AND DISPOSAL: Do not contaminate water, food, or feed by storage or disposal.
STORAGE: Keep from freezing. Store only in original tightly sealed container and out of reach of children
If empty: Do not reuse this container. Place in trash or offer for recycling if available.
If partly filled: Call your local solid waste agency or 1-800-CLEANUP for disposal instructions. Never place unused product down any indoor or outdoor drain.

WARRANTY STATEMENT: To the extent required by law, Pharm Solutions Inc. warrants that the product conforms to its chemical description and is reasonably fit for the purposes stated on the label only when used in accordance with the label directions. Pharm Solutions Inc. makes no other express or implied warranties either of merchantability or fitness for a particular use and shall not be liable for misuse or conditions beyond its control, such as handling or storage**.**

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Lawn Care / Weed Control

BURNOUT II

Weed & Grass Killer

Made of a special blend of vinegar and lemon juices and other patented synergistic components, BurnOut works faster and more efficiently than most existing weed controls. Simply spray it on and look for wilting within minutes (typical: 20 minutes on dandelion).

You'll see amazing results in three hours and dead weeds and grass by morning. A second shot takes unwanted plants right down to their roots.

Hailed by Gardener Broadcaster, Ralph Snodsmith, University Researchers, Botanical Gardens, and used by the New York Port Authoirity at the Governors Mansion in Albany.

BurnOut can be used on walkways, driveways, shrubbery beds and any where else as a post defoliant to control weeds and unwanted grass. Annuals are killed right away with BurnOut, while perennials may regenerate after a single application and require additional treatment.

For non-selective control of herbaceous broadleaf and grass weeds. Try it on most plants. Use safely around trees and shrubs.

The 2.5 gallons concentrate makes 7.5 gallons (3:1) and will cover a half of an acre in broadcast application.

Burnout II Concentrate	Burnout II Ready to Use
Active Ingredients:	Active Ingredients:
Clove Oil 18%	Clove Oil 6%
Citric Acid 30%	Citric Acid ... 10%
Other Ingredients:	Other Ingredients:
Mineral oil, (USP), Water, Gum Arabic	Mineral oil, (USP), Water, Gum Arabic
Total Other 52%	Total Other 84%

PRODUCT COMPARISON		
BurnOut	**Roundup**	**Scythe Herbicide**
Works in hours Kills most roots May require re-treatment on older hardier plants. Once application has dried on Weed & Grass, rain will not tend to affect performance. After application it is safe to enter treated areas.	Works in 7-10 days Kills roots May require re-treatment on older hardier plants. Reapplication may be required after rain	Works in hours kills weeds and grasses fast May require re-treatment on older hardier plants Reapplication may be required after rain

SaferGro®
Leader of Safe and Organic Products
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NATURAL WET®

OMRI™ Listed

Organic Wetting Agent

Natural Wet is an organic wetting agent that contains complex sugar structures (saponins) extracted from the desert plant Yucca schidigera. Saponins help plants utilize nutrients and increase stress resistance. **Natural Wet** may also facilitate nutrient and water absorption into the plant, stimulate plant growth and development, and as a result increase crop yield.

Natural Wet's principle ingredients are saponins (sapogenin glycosides) derived from yucca plant extracts. The yucca plant has adapted to thrive in harsh environments. These plants produce the saponins to aid in their survival. Saponins aid in water penetration and nitrogen utilization. During times of heat and moisture stress **Natural Wet** can aid plants by helping regulate water usage and increase their tolerance to these stresses. Effects can be seen immediately after application.

Natural Wet is listed by the Organic Materials Review Institute (OMRI) and the Washington State Organic Food Program (WSDA-OFP) for use in organic production. The unique properties of the yucca extract found in **Natural Wet** help foliar spray applications of micronutrient and pesticide solutions spread and stick to the plant surface for better absorption and uptake.

Natural Wet can also help loosen up compacted soils. Saponins have a slight detergent quality to them. Which can help eliminate clods and get water to penetrate soils that have a history of poor water absorption.

Natural Wet makes an excellent wetting agent for clay soils and potting mixes.

Benefits of Using Natural Wet

- 100% Biodegradable
- 100% Natural
- 100% Organic
- Compatible with almost all products
- Reduces surface tension of liquids
- Helps reduce stress caused by drought
- Increases water uptake
- Suitable for organic production
- Increases water penetration into the soil
- Improves drainage and reduces salinity

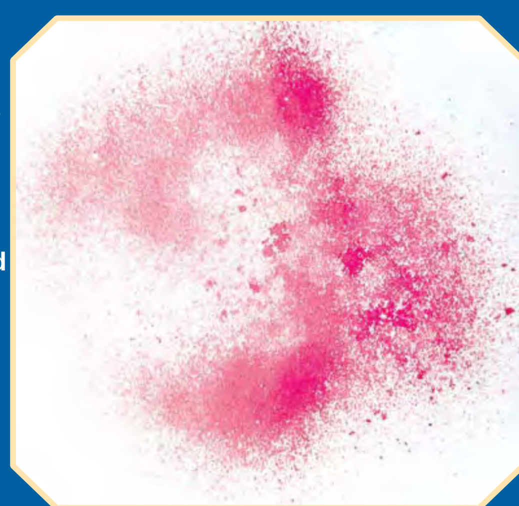
Adding **Natural Wet** to the irrigation water can help nutrients penetrate and adhere to hydrophobic soils or growing medias, allowing water to reach deeper into the root zone.

Natural Wet is ideal for organic growers who are looking for an OMRI listed spreader-sticker , and commercial growers who are looking for a safe, non-phytotoxic spreader-sticker. Hydroponic growers who use coconut coir and other hard to wet medias will find **Natural Wet** a welcome addition to their nutrient mixes. Desert growers, and those experiencing drought stresses, will benefit from applications of Natural Wet in the way of increased yields and stress reduction.

Natural Wet is a liquid formulation available in several package sizes including drums and totes. **Natural Wet** is recommended for use with Mildew Cure and Pest Out applications. **Natural Wet** is available from all SaferGro distributors.

Without Natural Wet the spray pattern and droplets are non-uniform and spread apart.

With Natural Wet the spray pattern and droplets are more uniform and diffused creating a sheeting effect when sprayed.



OTHER AVAILABLE PRODUCTS

- **ANT OUT** - Botanical Insecticide
- **MYCORMAX** - Biological Soil Inoculant
- **BIOMINS** - Encapsulated Micronutrients
- **FLORAGARD** - Cut Flower Preservative
- **MIXWELL** - Water & Soil Conditioner
- **BIOREPEL** - Natural Insect Repellent
- **WEED ZAP** - Organic Herbicide
- **MILDEW CURE** - Natural Powdery Mildew Fungicide
- **PHOSGARD** - Phosphite Fertilizer

SaferGro
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For labels and MSDS, visit our website at www.safergro.com or call us at 805.650.8918

SPECIMEN LABEL

MiLLER

NU-FILM-P®

STICKER — SPREADER

*ACTIVE INGREDIENT:	
Poly-1-p-Menthene	96%
INERT INGREDIENTS:	4%

*The amount of active ingredient in the formulation does not determine the activity. Activity is governed by the type of film which is formed and this is determined by refinement. The active ingredient in this product is Pinolene.®

GENERAL INFORMATION

NU-FILM-P is a superior STICKING agent designed for use with all pesticides. It is compatible in the spray tank with all commercially used pesticide products and soluble fertilizers.

NU-FILM-P forms a sticky, elastic film which tenaciously holds the pesticide on the crop foliage and greatly reduces rainfall and overhead irrigation erosion of the spray residue. The **NU-FILM-P** film will withstand about 1 inch of rainfall for seven to ten days, thus insuring that pesticide sprays are not lost shortly after application. **NU-FILM-P** will not foam, freeze or clog nozzles. It has been proven effective when applied by any aircraft or ground sprayer. It improves the initial pesticide deposit and allows excellent re-distribution of aircraft and concentrate sprayer deposits, to give complete coverage.

Under most conditions, apply sprays containing **NU-FILM-P** at least one hour before an anticipated rain. This time is needed for the film to set.

METRIC CONVERSION

1 Pt. Per Acre = 1.2 Liters Per Hectare
100 Gallons (U.S.) = 378.5 Liters
1 Hectare = 2.5 Acres (U.S.)

DIRECTIONS

To increase the efficiency of insecticidal, fungicidal and hormonal herbicide sprays, use 4 to 6 ounces of **NU-FILM-P** per acre.

For use in air blast, tree sprayers or hydraulic gun type sprayers, use at the rate of 4 to 6 ozs. per 100 gal. of water. When applied by aircraft, use at the rate of 4 to 6 ozs. per acre for all applications.

Johnsongrass control may be increased when **NU-FILM-P** is used at the rate of 1 pt. per acre with Dalapon sprays.

To insure maximum absorption of Foliar Nutrient Sprays, use 4 ounces of **NU-FILM-P** per acre.

Add **NU-FILM-P** to the spray tank as it is filling, with the agitator running. To insure good emulsification of this product, it is advisable to pre-mix **NU-FILM-P** with water before adding to the spray tank.

Rinse tank, lines and nozzles immediately after spraying, with water. After rinsing, there may still be a small amount of sticky residue in the tank. This will help to prevent rusting and corrosion. It will not clog nozzles when sprayer is next used. If spray happens to land on undesired surfaces, such as windows, cars, application equipment or others, it can be removed with water, before the spray deposit is dry or with kerosene after the film has dried or set.

The use of this material being beyond our control and involving elements of risk, we do not make any warranty, express or implied, as to the effects of such use, when this product is not used in accordance with the directions as stated on this label.

CAUTION: KEEP OUT OF REACH OF CHILDREN

Manufactured by

MILLER CHEMICAL & FERTILIZER CORPORATION

Hanover, Pennsylvania 17331, U.S.A. • An Alco Standard Company

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OVER

Corn Gluten Meal -- Byproduct to Wonder Product

by Viveka Ransom, Reporter for *The Iowa Horticulturist* and
Student in the Department of Horticulture, Iowa State University, 4915 Todd Drive #24 Ames, Iowa 50014

Does corn gluten meal kills weeds? Yes. This natural byproduct of the wet-milling process of corn represents a big step in the continuing effort by scientists to find alternatives to synthetic pesticides. The development began in 1986 when researchers at Iowa State University were studying the effects of *Pythium* (fungus disease organism) on the growth of grass.

The researchers used food-grade corn meal as a growth media for the *Pythium*. The experiment included test plots inoculated with corn meal cultures, plots that only had corn meal and no *Pythium*, and controls. Although the attempt to establish *Pythium* in the treated plots failed, the researchers observed reduced growth of bentgrass in the test plots that received fresh cornmeal.

"The reason for this inhibition was uncertain," said Dr. Christians, professor of Horticulture, who headed the project. "One possible explanation was that there was some type of organic compound contained in the fresh cornmeal that was destroyed by the activity of the fungal organism."

Research into the use of cornmeal began in earnest. All parts of the processed corn grain were tested. The results of the tests confirmed that corn gluten meal has the ability to stop root formation. With no roots, the plants died. The key to this was timing. The meal stopped root formation at the time of germination. After germination, it had no effect. However, the nitrogen contained in the material continued to spur growth. Dr. Christians had discovered a natural "weed-and-feed" product. Further field trials demonstrated the merits of this material. It was granted a patent in 1991.

Corn gluten meal is used in cattle and poultry feed and in fish and dog food. It is a sixty-percent corn protein material that contains ten-percent nitrogen. Though produced as a fine, yellow powder, it can be pelletized for easier application to the soil. It offers pre-emergent control of weeds like dandelions, pigweed, crabgrass, plantain, lambs quarters, and curly dock.

Timing, as mentioned previously, is important. The corn gluten meal must be applied before the seed of the target weeds emerges above the soil. "The application should be made close to the time of weed germination. Moisture is necessary to activate the material, but extended wet periods can reduce its effectiveness," warns Dr. Christians. While the lawn is the prime site for many weeds, corn gluten meal can be used in flowerbeds and vegetable plots.

Because the product contains nitrogen, it also acts as an excellent fertilizer to plants that have gone beyond the germination stage. "Later work has repeatedly shown that corn gluten meal compares to the best commercially-available natural fertilizers," says Dr. Christians. The current recommended rate of application is 20 pounds of product per 1,000 square feet. At 10 percent nitrogen by weight, this equates to a nitrogen application of 2 pounds per 1,000 square feet. However, always read and follow application rates provided on the package labels.

Christians Recognized As Inventor of the Year

The Iowa Intellectual Property Law Association chose Dr. Nick Christians as the 1998 Iowa Inventor of the Year. At the association's annual banquet on October 30, 1998, he was presented an award in recognition of his discovery of the properties and uses for corn gluten meal as a natural environmentally friendly lawn herbicide.

Where to Buy Corn Gluten Meal in Iowa and Nearby:

Corn gluten meal is available at garden centers and hardware stores or by mail order as the following brand name products.

- Corn Gluten Meal Herbicide -- Arlyn Hofland, 403 36th Street Place, Sioux City, IA 51104, phone 712-258-2375
- Corn Gluten Meal Herbicide -- Grain Processing Co., 1600 Oregon Street, Muscatine, IA 52761, phone 319-264-4211
- DynaWeed -- Soil Technologies Corp, 2103 185th Street, Fairfield, IA 52556, phone 515-472-3963 or 800-221-7645
- Earth Friendly -- Cereal Byproducts, Inc., P.O. Box 575, Mount Prospect, IL 60050, phone 847-818-1550
- ProPac -- Manning Agricultural Center, Inc., 619 Julia Street, Manning, IA 51455, phone 712-653-2981 or 800-248-4409
- Safe Earth Natural Weed Control -- Safe Earth Lawn and Garden, 900 52nd Street, West Des Moines, IA 50265, phone 515-222-1997
- W.O.W! -- Gardens Alive!, 5100 Schenley Place, Lawrenceburg, IN 47025, phone 812-537-8651 (the name 'A-MAIZING LAWN' was discontinued and the product has now been renamed and is now available as W.O.W!).

Corn Gluten Meal is Patented

Corn gluten meal was patented as a natural weed control in 1991 and was registered with the Environmental Protection Agency as a herbicide in August 1994. It was marketed under the name 'A-MAIZING LAWN' in 1995 and 1996. Sales went well. Researchers continue to evaluate other items related to the material. Two other patents on the use of natural products for weed control were issued in 1994 and were under evaluation in 1995. Further research with turfgrass and strawberries are presently being conducted.

HOW TO USE CORN GLUTEN MEAL

NICK CHRISTIANS
Iowa State University

Corn gluten meal works by inhibiting the root formation of germinating plants. It generally does not inhibit the roots of mature plants or transplants until your reach very high rates (80 pounds/1000 ft^2 or higher). It should be applied before germination of the weeds. The weed will germinate and usually forms a shoot, but does not form a root. After germination, a short drying period is needed to kill the plants that have germinated but have not formed a root. Timing is critical. If it is too wet during germination, the plants will recover and form a root. (This is also true of chemical preemergence herbicides).

It is preemergence only, there is no postemergence effect on established weeds. In fact, it makes a great fertilizer for germinated weeds.

If it does not rain in 5 days of application, water it in with approximately .25 inches of water. Then leave a drying period after germination.

It will usually work for about 5 to 6 weeks following germination.

Rates will vary depending on crop and target weed. I generally recommend 20 lbs product per 1000 ft^2. This provides about 1 lb of nitrogen per 1000 ft^2. Some crops that are grown in rows can be treated in bands in the row and weeds can be tilled between rows. This makes it more economical to use in crop production. Test the material at rates from 10 lbs/1000 ft^2 in 10 pound increments to as high as 80 lbs/1000 ft^2.

It does not work well with seeded garden crops unless they are seeded deeply (radishes seem to be the exception and there may be others). Transplants or mature plants generally work well. Some producers put down a band, work it into the upper inch of soil, and then put the transplant in the band.

In garden and crop production, growers generally work out their own system, depending on their understanding of the crop they are growing and the weeds they are trying to control.

The material is generally about 10% nitrogen by weight. One hundred pounds has 10 lbs of nitrogen.

The nitrogen will release slowly over a 3 to 4 month period after application.

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Greenhouse Screening of Corn Gluten Meal as a Natural Control Product for Broadleaf and Grass Weeds

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Additional index words. corn by-product, weed management, natural herbicide, pest management

Abstract. **Corn (*Zea mays* L.) gluten meal (CGM) was evaluated under greenhouse conditions for efficacy on 22 selected monocotyledonous and dicotyledonous weed species. Corn gluten meal was applied at 0, 324, 649, and 973 g·m^{-2} and as a soil-surface preemergence (PRE) and preplant-incorporated (PPI) weed control product. CGM reduced plant survival, shoot length, and root development of all tested species. Black nightshade (*Solanum nigrum* L.), common lambsquarters (*Chenopodium album* L.), creeping bentgrass (*Agrostis palustris* Huds.), curly dock (*Rumex crispus* L.), purslane (*Portulaca oleracea* L.), and redroot pigweed (*Amaranthus retroflexus* L.) were the most susceptible species. Plant survival and root development for these species were reduced by ≥75%, and shoot length was decreased by >50% when treated PRE and PPI with 324 g CGM/m^2. Catchweed bedstraw (*Galium aparine* L.), dandelion (*Taraxacum officinale* Weber), giant foxtail (*Setaria faberi* Herrm.), and smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex Muhl] exhibited survival and shoot length reductions >50% and an 80% reduction in root development when treated with PPI CGM at 324 g·m^{-2}. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and velvetleaf (*Abutilon theophrasti* Medic.) were the least susceptible species showing survival reductions ≤31% when treated with 324 g CGM/m^2.**

Synthetic herbicides often are used for weed control in vegetable crop and turfgrass management systems. Public awareness of the widespread use of herbicides and the possible negative effects of their residues on the environment are incentives for researchers to identify natural plant substances with herbicidal properties.

Several researchers have reported inhibition of shoot and root elongation of selected plant species by corn stalks and residue (Bonner, 1950; Nielsen et al., 1960). Water-soluble extracts from cornstalks significantly inhibited the root and shoot growth of wheat (*Triticum aestivum* L.) and sorghum [*Sorghum bicolor* (L.) Moench.] seedlings (Guenzi and McCalla, 1962). In addition, aqueous extracts from decomposing corn residues suppressed root elongation in lettuce (*Lactuca sativa* L. 'Great Lakes'), suggesting that inhibition resulted from damage to the meristematic tissue of the emerging radicles (Chou and Patrick, 1976). Recent research has shown that corn gluten meal (CGM), the protein fraction of corn grain extracted in the wet-milling process, effectively controlled several weed species and has potential for use as a natural herbicide in turfgrass (Christians, 1993) and strawberry (*Fragaria* ×*ananassa* Duch.) weed management programs (Nonnecke and Christians, 1993).

Root formation during germination is inhibited by CGM in susceptible species. When CGM-treated plants were subjected to moisture stress, they died (Christians, 1993). In addition, CGM contains ≈10% N by weight and provides an additional N source to plant species with well-developed root systems. United States patent 5,030,268 has been granted for using CGM as a surface-applied preemergence herbicide (Christians, 1991).

Our objective was to evaluate the effects of CGM on plant survival and shoot and root growth of selected monocotyledonous and dicotyledonous weeds.

Materials and Methods

Twenty-two plant species were screened for susceptibility to CGM. The 10 dicotyledonous species used were black medic (*Medicago lupulina* L.), black nightshade, buckhorn plantain (*Plantago lanceolata* L.), catchweed bedstraw, common lambsquarters, curly dock, dandelion, purslane, redroot pigweed, and velvetleaf. Twelve monocotyledonous species were screened: annual bluegrass (*Poa annua* L.), barnyardgrass, creeping bentgrass, giant foxtail, green foxtail [*Setaria viridis* (L.) Beauv.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], orchardgrass (*Dactylis glomerta* L.), quackgrass [*Agropyron repens* (L.) Beauv.], shattercane (*Sorghum bicolor* L.), smooth crabgrass, woolly cupgrass [*Eriochloa villosa (*Thunb.) Kunth], and yellow foxtail [*Setaria lutescens* (Weigel) Hubb.].

All plants were grown under greenhouse conditions in square plastic pots with a surface area of 46.2 cm^2 and a depth of 5.7 cm. The planting medium was a Nicollet (fine-loamy mixed mesic Aquic Hapludolls) soil with a pH of 7.6 and 32 g organic matter/kg, 22 ppm extractable P, and 160 ppm exchangeable K. All seeds were planted to a depth of 0.6 cm. The number of seeds planted in each pot was species specific and was determined from previously obtained germination data (Table 1). Species with very small seeds were planted on a weight basis. Plants were watered to keep the soil uniformly moist, and no pesticides were applied. Because of the short duration of each test, no additional fertilizer was added.

CGM was applied at 0, 324, 649, and 973 g·m^{-2}. These treatment levels were selected based on previous greenhouse research (Christians, 1993). CGM was applied to the soil surface for the preemergence (PRE) treatments. For the preplant-incorporated (PPI) treatments, CGM was uniformly mixed in the upper 2.5 cm of soil in the pots.

Two studies were conducted in 1992, each with three replications: the first in late summer with natural lighting and the second in the fall using supplemental lighting from high-pressure sodium lamps to enhance the natural irradiance and to extend the daylength to 16 h. These lights delivered ≈70 μmol·m^{-2}·s^{-1} of irradiance.

The duration of each test was 16 days. On the last day, plant survival was assessed by counting the number of living plants in each pot, and shoot length was measured as the average length of the surviving plants. The soil residue was washed from the roots to examine the effects of CGM on rooting. The roots of CGM-treated plants were compared visually with the roots of nontreated plants. Differ-

Table 1. Number and weight of seeds planted in each pot for the 22 species of plants screened.

Plant species	No. seeds/pot	Wt seeds/pot (g)
Annual bluegrass	500	0.219[z]
Barnyardgrass	25	0.101
Black medic	50	0.074[z]
Black nightshade	15	0.020
Buckhorn plantain	200	0.500[z]
Catchweed bedstraw	25	0.077
Common lambsquarters	150	0.120[z]
Creeping bentgrass	1000	0.200[z]
Curly dock	100	0.078[z]
Dandelion	15	0.008
Giant foxtail	25	0.040
Green foxtail	50	0.055
Large crabgrass	500	0.200[z]
Orchardgrass	50	0.060
Purslane	100	0.080[z]
Quackgrass	30	0.097
Redroot pigweed	25	0.007
Shattercane	30	0.490
Smooth crabgrass	100	0.200[z]
Velvetleaf	15	0.142
Woolly cupgrass	15	0.126
Yellow foxtail	15	0.046

[z]Because of the small seed size of these species, they were planted on the basis of weight per pot. The number of seeds per pot is a mean count.

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ences between the amount of rooting for CGM-treated plants and nontreated plants were estimated and recorded as percent reductions in root development. Reductions were estimated in 5% increments.

The statistical design was a split-split plot. The four CGM treatment levels were the whole-plot treatments; the two application methods, the subplot treatments, and the weed species the sub-subplots. The results were similar for the two studies; therefore, data from both were combined for analysis.

The three replications in the first study were run consecutively because of space limitations, and those for the second study were run concurrently. Data were analyzed with the SAS version 6.6 (SAS Institute, 1990) analysis of variance procedure to test the significance of CGM effects on plant survival, shoot length, and root development. Least significant difference tests were used to compare significantly different means (Cochran and Cox, 1957).

Results

Plant survival. CGM reduced the survival of all broadleaf and grass species (Tables 2 and 3). There were no differences in the survival of plants receiving PRE applications and PPI treatments (Table 2).

There was a wide degree of interspecific variation in plant survival of CGM-treated plants (Table 3). Survival of all species, except barnyardgrass, green foxtail, quackgrass, velvetleaf, and woolly cupgrass, was reduced ≥40% when treated with 324 g CGM/m^2, and eight broadleaf species incurred 75% reductions at this CGM level. Reductions in survival were ≥75% for 11 of the species treated with 649 g CGM/m^2, and the survival of six additional species was reduced >40%. At 973 g CGM/m^2, survival was reduced ≥63% for all species except barnyardgrass, shattercane, and velvetleaf (Table 3).

There also were differences among species in their response to CGM quantity (Table 2). Survival decreased for 15 broadleaf and grass species as the amount of applied CGM increased (Table 3). Survival reductions were ≥95% for purslane and ≥87% for redroot pigweed at all CGM quantities. The survival of 20 species was decreased ≥50% by 973 g CGM/m^2, and eight broadleaf and four grass species experienced reductions ≥90%. Survival was reduced ≤51% at all CGM levels for barnyardgrass, shattercane, and velvetleaf.

Seven broadleaf and one grass species had the fewest survivors. At 324 g CGM/m^2, survival of black nightshade, buckhorn plantain, common lambsquarters, creeping bentgrass, curly dock, dandelion, purslane, and redroot pigweed was reduced ≥75%. Annual bluegrass, catchweed bedstraw, giant foxtail, large crabgrass, orchardgrass, and smooth crabgrass showed survival reductions ≥51% at 324 g CGM/m^2. At this same CGM level, all quackgrass and velvetleaf plants survived, as did nearly all woolly cupgrass seedlings.

Shoot length. There was a wide range of interspecific variation in shoot length reduction at the various CGM treatment levels (Table 2). Shoot lengths decreased for 13 broadleaf and grass species as the amount of applied CGM increased (Table 4). Black medic, black nightshade, common lambsquarters, curly dock, dandelion, purslane, and redroot pigweed had shoot lengths >50% shorter than the control at all CGM levels. Green foxtail receiving PRE applications exhibited 0% reduction in shoot length at 324 g CGM/m^2, 10% at 649 g CGM/m^2, and did not grow at 973 g CGM/m^2. At 649 g CGM/m^2 black nightshade died, and buckhorn plantain, curly dock, dandelion, and redroot pigweed had ≥80% less shoot growth than the control for PRE and PPI CGM. Curly dock and redroot pigweed exhibited >90% shoot reduction, and black nightshade, common lambsquarters, dandelion, and green foxtail died with PRE and PPI at 973 g CGM/m^2.

The species × application method interaction was significant for shoot length (Table 2). Most species treated with PPI CGM had shorter shoots than those treated with PRE applications (Table 4). Shoot lengths of buckhorn plantain, catchweed bedstraw, giant foxtail, green foxtail, and quackgrass were reduced ≤22% by 324 g PRE CGM/m^2 but were reduced ≥50% by PPI applications at this level. With PRE at 649 g CGM/m^2, large crabgrass, and yellow foxtail exhibited shoot reductions of 6% and 0%, respectively, but with PPI CGM at this level, they showed reductions of 49% and 87%, respectively. Treatment with a PRE application at 973 g CGM/m^2 reduced shoot length ≤32% for quackgrass, shattercane, woolly cupgrass, and yellow foxtail; shoot lengths of barnyardgrass and large crabgrass were not reduced. PPI applications of 973 g CGM/m^2, however, resulted in ≥51% shoot length reductions for all species, and shoot lengths were decreased 55% for barnyardgrass and 87% for large crabgrass.

Root development. Rooting of all broad-

Table 2. Analysis of variance for a split-split-plot design showing the significance of corn gluten meal effects on plant survival, shoot length, and root development.[z]

		$P > F$		
Source	df	Plant survival	Shoot length	Root development
Replication (Rep)	5	0.0008	0.0007	0.0001
Corn gluten meal (CGM)	3	0.0001	0.0001	0.0001
Rep × CGM[y]	15	0.1463	0.3182	0.0018
Application method (AM)	1	0.4864	0.0001	0.0001
Species	21	0.0001	0.0001	0.0001
AM × species	21	0.1188	0.0056	0.0001
Rep × AM × species[x]	215	0.0001	0.0001	0.0001
CGM × AM	3	0.5160	0.0015	0.0001
CGM × species	63	0.0054	0.0001	0.0001
CGM × AM × species	63	0.2691	0.0532	0.0003
Error (c)	645			

[z]Data from both studies were combined.
[y]This source is error (a).
[x]This source is replication × application method × species and is error (b).

Table 3. Reductions in survival, relative to the control, of weeds treated with three quantities of corn gluten meal (CGM).[z]

	% Reduction[y]		
Weed	Quantity of CGM		
species	324 g·m^{-2}	649 g·m^{-2}	973 g·m^{-2}
Annual bluegrass	60	81	72
Barnyardgrass	31	35	41
Black medic	49	63	63
Black nightshade	78	99	100
Buckhorn plantain	80	95	96
Catchweed bedstraw	66	33	94
Common lambsquarters	82	88	99
Creeping bentgrass	85	85	96
Curly dock	75	94	97
Dandelion	75	90	100
Giant foxtail	63	54	83
Green foxtail	37	78	100
Large crabgrass	51	70	82
Orchardgrass	56	53	92
Purslane	97	95	100
Quackgrass	0	20	71
Redroot pigweed	87	96	99
Shattercane	42	43	51
Smooth crabgrass	51	85	97
Velvetleaf	0	18	35
Woolly cupgrass	6	29	79
Yellow foxtail	43	65	78

[z]Least significant difference ($LSD_{0.05}$ = 40) for mean comparisons among CGM quantities for each species.
[y]These data include the results of two studies and are mean percentages of the surface-applied (PRE) and preplant-incorporated (PPI) survival reductions relative to the survival of the control plants (n = 12).

leaf and grass species was reduced by CGM (Tables 2 and 5). Reduction in root development significantly differed among CGM levels and species (Table 2). Interspecific variation in rooting ranged widely at all CGM levels (Table 5). With increasing amounts of applied CGM, root development decreased for black nightshade, buckhorn plantain, common lambsquarters, dandelion, quackgrass, and smooth crabgrass. Rooting reductions were ≥80% at all PRE and PPI levels for black medic, black nightshade, curly dock, creeping bentgrass, and purslane. Buckhorn plantain, catchweed bedstraw, common lambsquarters, dandelion, giant foxtail, green foxtail, orchardgrass, smooth crabgrass, and yellow foxtail had root development reduced >80% at all PPI levels. Rooting decreased ≤45% at all PRE CGM levels for barnyardgrass, large crabgrass, shattercane, and woolly cupgrass.

The species × application method interaction was significant (Table 2). Dandelion, green foxtail, and yellow foxtail had ≤35% rooting reductions when treated with 324 g PRE CGM/m² but exhibited ≥90% reductions when subjected to PPI applications at the same level (Table 5). Large crabgrass root development was not decreased with 324 g PRE CGM/m² but was reduced 80% with 324 g PPI CGM/m². Root development reductions were ≤55% for annual bluegrass, catchweed bedstraw, large crabgrass, woolly cupgrass, and yellow foxtail with 649 g PRE CGM/m² but were ≥90% with 649 g PPI CGM/m². PPI applications at 973 g CGM/m² resulted in ≥75% root development reductions for all species. PRE applications at this CGM level, however, reduced rooting ≤45% for barnyardgrass, large crabgrass, shattercane, and woolly cupgrass.

Rooting decreased unequally among species in the same genus. When treated with 324, 649, and 973 g PRE CGM/m², large crabgrass exhibited 0%, 0%, and 45% root reductions, respectively, and smooth crabgrass had 65%, 95%, and 100% reductions, respectively. Rooting reductions for yellow foxtail treated with 324, 649, and 973 g PRE CGM/m² were 20%, 20%, and 60%, respectively. At the same levels, reductions were 65%, 85%, and 95%, respectively, for giant foxtail and 35%, 85%, and 100%, respectively, for green foxtail.

Discussion

The results of these greenhouse screenings substantiate that the efficacy of CGM as a herbicide may extend to a broad spectrum of monocotyledonous and dicotyledonous plant species (Christians, 1993). All broadleaf and grass species evaluated exhibited some degree of susceptibility to the herbicidal properties of CGM. Plant responses, however, were variable among treatment levels and species. Application method also affected the reductions in shoot length and root development.

The PPI treatments generally were more effective than PRE applications in reducing shoot length and root development in all species, probably due to increased contact between the CGM and the germinating seedlings with the PPI treatment. The roots and shoots of rapidly germinating species may be developed too fully before the PRE treatments become effective.

The efficacy of CGM for control of a particular weed species in a management system depends on the amount of CGM applied. Broadleaf species were generally more susceptible to CGM than grasses, and reductions in shoot length and root development were larger at the lower CGM levels. Black nightshade, common lambsquarters, creeping bentgrass, curly dock, purslane, and redroot pigweed were the most susceptible species and exhibited ≥75% reductions in survival and rooting and >50% reductions in shoot length with PRE and PPI at 324 g CGM/m².

Table 4. Reductions in shoot lengths, relative to the control, of weeds treated with three quantities of soil-surface-applied (PRE) and preplant-incorporated (PPI) corn gluten meal (CGM).[z]

	% Reduction[y]					
	Quantity of CGM					
Weed	324 g•m⁻²		649 g•m⁻²		973 g•m⁻²	
species	PRE	PPI	PRE	PPI	PRE	PPI
Annual bluegrass	27	39	41	29	49	51
Barnyardgrass	0	12	0	30	0	55
Black medic	51	59	73	75	92	87
Black nightshade	66	85	100	100	100	100
Buckhorn plantain	22	67	81	89	90	89
Catchweed bedstraw	11	70	46	100	81	100
Common lambsquarters	70	74	74	95	100	100
Creeping bentgrass	47	58	70	70	95	75
Curly dock	55	75	84	89	90	94
Dandelion	54	81	83	90	100	100
Giant foxtail	21	56	51	72	64	93
Green foxtail	0	62	10	94	100	100
Large crabgrass	0	4	6	49	0	87
Orchardgrass	34	34	45	44	70	88
Purslane	65	100	66	95	83	100
Quackgrass	7	50	27	72	22	94
Redroot pigweed	74	81	81	94	95	100
Shattercane	45	41	19	64	10	84
Smooth crabgrass	44	53	70	71	86	89
Velvetleaf	20	0	42	0	58	79
Woolly cupgrass	11	12	18	50	31	81
Yellow foxtail	0	28	0	87	32	84

[z]Least significant difference ($LSD_{0.05}$) = 21 for mean comparisons between PRE and PPI application methods for each species, and $LSD_{0.05}$ = 30 for mean comparisons among CGM quantities for each species.
[y]These data include results of two studies and are the mean percentages of the shoot length reductions relative to the shoot lengths of the control plants (n = 6).

Table 5. Reductions in root development, relative to the control, of weeds treated with three quantities of soil-surface-applied (PRE) and preplant-incorporated (PPI) corn gluten meal (CGM).[z]

	% Reduction[y]					
	Quantity of CGM					
Weed	324 g•m⁻²		649 g•m⁻²		973 g•m⁻²	
species	PRE	PPI	PRE	PPI	PRE	PPI
Annual bluegrass	50	70	55	90	95	95
Barnyardgrass	0	35	10	50	30	75
Black medic	80	95	80	95	100	100
Black nightshade	85	100	100	100	100	100
Buckhorn plantain	70	80	95	100	100	100
Catchweed bedstraw	45	80	55	100	100	100
Common lambsquarters	75	100	90	100	100	100
Creeping bentgrass	95	90	100	100	100	100
Curly dock	90	90	100	100	100	100
Dandelion	30	90	95	100	100	100
Giant foxtail	65	85	85	85	95	95
Green foxtail	35	95	85	100	100	100
Large crabgrass	0	80	0	90	45	100
Orchardgrass	50	80	85	95	95	100
Purslane	80	100	80	100	85	100
Quackgrass	25	75	60	95	75	100
Redroot pigweed	95	100	100	100	100	100
Shattercane	5	45	30	75	25	95
Smooth crabgrass	65	90	95	100	100	100
Velvetleaf	40	60	70	75	70	90
Woolly cupgrass	15	60	20	90	35	100
Yellow foxtail	20	90	20	100	60	100

[z]Least significant difference ($LSD_{0.05}$ = 12) for mean comparisons between PRE and PPI application methods for each species, and $LSD_{0.05}$ = 17 for mean comparisons among the CGM quantities for each species.
[y]These data include results from two studies and are the mean percentages of the root development reductions relative to the root development of the control plants (n = 6).

Turfgrass management systems are restricted to PRE applications of CGM. According to survival, shoot length, and rooting reductions, PRE applications of CGM may provide acceptable control of annual bluegrass, black nightshade, buckhorn plantain, catchweed bedstraw, common lambsquarters, curly dock, dandelion, giant foxtail, orchardgrass, purslane, redroot pigweed, and smooth crabgrass. In addition, competition from the mature grasses in turfgrass areas may increase the degree of weed control.

Corn gluten meal has the potential to be used as a natural herbicide for the control of many broadleaf and grass weed species. More field trials than those of Christians (1993), however, are necessary to confirm the efficacy of CGM for specific weed species in competitive turfgrass and strawberry production systems.

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Flamers

Flame Weeding for Vegetable Crops (ATTRA)

Flaming as a Method of Weed Control in Organic Farming Systems (MSU)

Flame Weeding for Vegetable Crops

Current Topic

By Steve Diver
NCAT Agriculture Specialist
June 2002

Introduction

Flame weeding—a type of *thermal* weed control—was commonly used in row crops like cotton and sorghum from the late 1930s until the mid-1960s, when selective herbicides became widely available. In the 1980s and '90s, flame weeding made a rapid comeback as a non-chemical weed control technique, especially among organic farmers.


Photo courtesy of Flame Weeders, Glenville, WV

Flame weeding, also called flame cultivation, relies on propane gas burners to produce a carefully controlled and directed flame that briefly passes over the weeds. The intense heat *sears* the leaf, causing the cell sap to expand and disrupt cell walls. Foliage that retains a thumb print when pressure is applied between your thumb and finger has been adequately flamed. The flamed weeds soon wilt and die, usually in one to three days.

Weeds are most susceptible to flaming when they are seedlings, 1 or 2 inches tall. Broadleaf weeds are more susceptible to lethal flaming than grasses. Grasses develop a protective sheath by the time they are approximately 1 inch tall and may require a second flaming. Repeated flaming can likewise be used to suppress perennial weeds such as field bindweed.

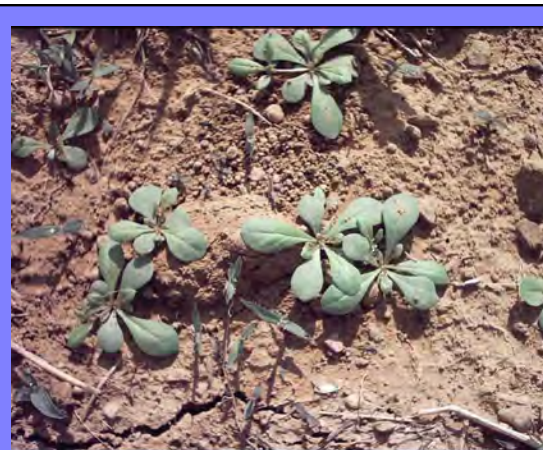
Flame weeders come in a range of human- and tractor-powered models. Market-farming equipment options include hand-held single-torch flamers, as well as push-wheeled multiple-torch flamers mounted under a flame hood. Tractor-powered kits are available in 2, 4, 6, and 8-row models, with or without a flame hood; other options include a complete toolbar setup with accompanying cultivator attachments for between-row mechanical cultivation.

Farmer feedback on flame weeding has been positive. Joe Fitzgerald, a farmer near Dubuque, Iowa, reported that "a blind person can see the difference in weed control" between flamed and unflamed organic corn, even though both plots had also been rotary-hoed and cultivated (1).

ATTRA is the national sustainable agriculture information service operated by the National Center for Appropriate Technology under a grant from the Rural Business-Cooperative Service, U.S. Department of Agriculture. These organizations do not recommend or endorse products, companies, or individuals. ATTRA is headquartered in Fayetteville, Arkansas (P.O. Box 3657, Fayetteville, AR 72702), with offices in Butte, Montana and Davis, California.

Pre-emergent Flaming

Controlling weeds before the crop emerges is known as pre-emergent weed control. In vegetable crops, there are two distinct ways to use pre-emergent flaming: the stale seedbed technique and the peak emergence technique.



Stale Seedbed Technique

The stale seedbed technique is a form of early-season weed control in direct-seeded crops. Seedbed preparation and soil stirring—for example, hilling the soil into beds—always results in a flush of weeds. With this technique, instead of sowing vegetable seeds into freshly prepared soil, planting is delayed. The aim is to knock down the early-germinating weeds, and perhaps a second flush of weeds, without further soil tillage (which would bring new weed seeds to the surface). The vegetable crop is then seeded into a weed-free bed. Most often, shallow tillage or herbicides are used to knock down the flush of weeds, but flaming is an alternative technique. Growers will sometimes pre-irrigate to induce more weed growth before flaming.

This technique can also be used to prepare a stale seedbed prior to setting out transplants. Essentially, you are helping your vegetable crops get off to a good start by eliminating early-season weed competition. Once the vegetable canopy forms, shade reduces weed germination; weed seedlings that do sprout can be controlled by mechanical cultivation.

Flame off the first flush of weeds for a clean seedbed.

The *critical weed-free period* is the minimum length of time a crop must remain nearly weed-free to prevent reductions in yield or quality. For most vegetables, this is usually the first quarter or third of their growing period—something like four to six weeks after seedling emergence, and slightly less for transplants. Weeds emerging after this period have less impact on vegetable yields than early-season weeds.

Critical Weed-Free Periods for Selected Weeds in Vegetable Crops

Crop	Location of Study	Critical Weed-Free Period*	Major Weeds Present
Snap beans	NJ, MA	Emergence to Full Bloom, 2 to 4 WAE	cocklebur, purslane
Cabbage (transplanted)	Ontario	3 to 4 WAP	lambsquarters, pigweed, crabgrass, green foxtail
Muskmelon	Israel	4 to 6 WAE 0 to 3 WAE	pigweed species, smooth amaranth
Onions	OR	All season	redroot pigweed
Summer squash	CT	4 to 6 WAT	quackgrass, lambsquarters, ragweed
Sweetpotato	Phillipines	2 to 4 WAT	grasses, morningglory
Tomato (bare ground)	Ontario	28 to 35 DAT	lambsquarters, ragweed, pigweed, crabgrass, foxtail, purslane
Watermelon	NC	2 to 4 WAT	large crabgrass

*WAE: weeks after emergence; WAP: weeks after planting; DAT: days after transplanting; and WAT: weeks after transplanting.

Source: Sustainable Practices for Vegetable Production in the South
Dr. Mary Peet, North Carolina State University
http://www.cals.ncsu.edu/sustainable/peet/IPM/weeds/c07weeds.html

Peak Emergence Technique

In the peak-emergence flaming technique, vegetable seeds are promptly sown after seedbed preparation. Just before vegetable seedlings emerge, the bed is flamed to kill seedling weeds (which tend to sprout faster). The aim is to eliminate the first flush of weeds and catch the seedling weeds when they are young and susceptible, while avoiding damage to the vegetable crop (2, 3).

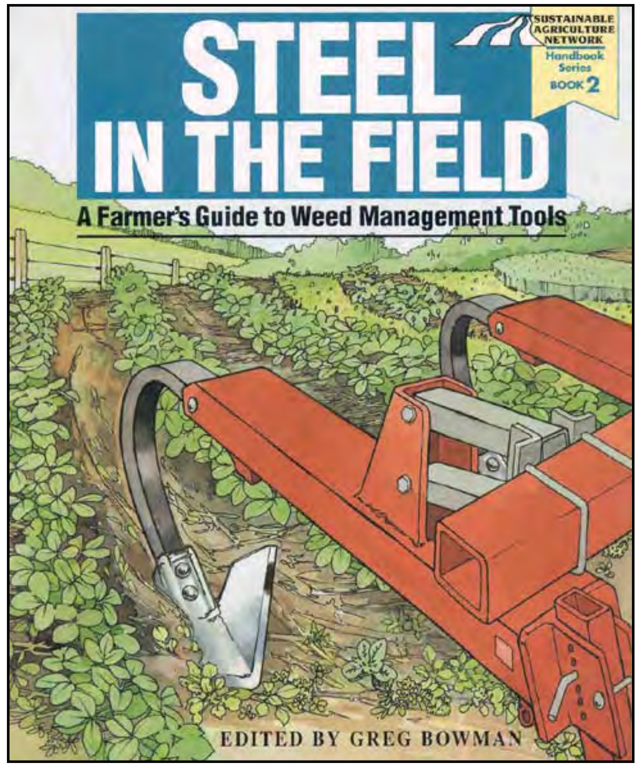
This second method is especially well suited to slow-germinating, direct-seeded crops like carrots and parsnips. At optimum soil temperatures, carrots germinate approximately seven to eight days after planting. In this case, weeds would be flamed off after five or six days. However, carrots are commonly planted in cool soils and germination may take as long as 14 to 21 days. Consequently, it's best to dig into the row to check on the progress of seedlings and time the flaming accordingly. Some growers place a pane of glass or plastic strip over a small section of the bed to speed up carrot seed germination. The field is flamed when the carrots under the glass emerge. The rationale is that the carrots in bare soil will typically emerge a few days later.

In European trials, flaming alone reduced weed populations in carrot beds by 80 percent (3).

As carrots are particularly difficult to weed, this technique is a real boost to organic farmers. Steve Meyer, a market gardener in West Virginia who flames carrots, onions, and beets, said, "The difference in weed control between flamed and unflamed beds is like night and day" (4).

Following flaming, and for the duration of the growing season, a mechanical weed-control system can be used for carrots, employing specialized cultivators (finger weeders, inter-row brush hoes, steerage hoes) or standard cultivators and wheel hoes. Refer to *Steel in the Field: A Farmer's Guide to Weed Management Tools*, a practical handbook from the Sustainable Agriculture Network, for descriptions and illustrations of mechanical cultivation tools (5).

The following table shows the approximate number of days to carrot seedling emergence at various soil temperatures, when seeds are planted ½ inch deep.



Steel in the Field, SAN Publications

DAYS TO EMERGENCE FOR CARROTS AT DIFFERENT SOIL TEMPERATURES

Soil temp. (°F)	32	41	50	59	68	77	86
Days to emergence	NG*	51	17	10	7	6	6

*NG=No germination

Source: Lorenz, Oscar A. and Donald N. Maynard. 1980. Knott's Handbook for Vegetable Growers. 2nd ed. Wiley-Interscience, John Wiley & Sons, New York. p. 56

To increase the effectiveness of flame weeding on vegetable beds for carrots and other direct-seeded crops, Thermal Weed Control Systems, Inc. of Neillsville, Wisconsin, offers a flame hood similar to those used in Europe. Ron Jones of Thermal Weed Control Systems calls it a "hover burner." The tractor-drawn models he manufactures have 5 to 7 burners, and cost in the neighborhood of $2,250. Jones explained that lettuce growers are also using the hover burner between sequential crop plantings to control insect and disease problems. Flame Weeders, a small company in West Virginia, manufactures push-flamers for market farmers that are wheel-mounted with flaming hoods; these range in price from $300 to $400.

An Australian report provided the following summary of pre-emergence flaming (6):

"Pre-emergence technique used by organic farmers was tested and adapted to Australian conditions. This technique was used one day before seeding and one day before emergence on carrots and onions. The first manual weeding (hand hoeing) was completely eliminated. A labor cost for hand weeding a plot 1m x 100 m was reduced from $160 to $2.50 LPG [Liquid Propane Gas] cost.

"Only one flame treatment was used for sweet potatoes and lettuce one day before the seedlings were transplanted into the ground. One row of sweet potatoes was 95% weed free for four months (from transplanting to harvesting). The lettuces were without weeds for one month between planting seedlings to harvest.

"We recommend one heat treatment for the crops with good ability to suppress weeds such as beans, pumpkins, sweet potatotes, potatoes, cucumbers, melons, sweet corn and transplanting crops. Two passes are recommended for the crops with poor ability to suppress weeds such as radishes, carrots, greens, onions, tomatoes, lettuce, broccoli and cabbage.

"Cleanup of a seed bank is possible with multiple passes (up to five). In spring and early summer the second treatment will often have to take place from a week to at most 10 days after the first. The third treatment follows after 10 to 12 days, the fourth 2 to 3 weeks later and the fifth 4 to 6 weeks thereafter. The best results are achieved by sticking to the schedule and when the weeds are between 1 and 2 cm in height."

Post-emergent Flaming

Flame weeding can be applied *after* the vegetable crop has emerged by directing the flame away from the crop plants, by shielding the crop, or by flaming at a time when crop stems are resistant to heat. This method is also known as "selective flaming." Directing flames into the crop row is a scary thought, but some plants can withstand the heat, especially after they've put on sufficient vegetative growth. The result is a non-chemical means of *in-row* weed control; for organic farmers, this is a significant tool. For example, see the pictures on flame weeding for corn at *Reducing Herbicide Usage on the Farm*, a joint project of Agricultural Utilization Research Institute (AURI) and Sustainable Farming Association of Minnesota (SFA), at: <http://www.auri.org/proproj/flamewee.html>.

Reports from the literature include the following examples:

- Sweet corn can be flamed when it reaches a height of 4 inches, and thereafter until it reaches canopy.
- Irish potatoes are flamed to control Colorado potato beetle, achieving 70–80% reduction of overwintering adults and 35% reduction of hatching eggs.
- Tomato plants can be flamed with very little stress when transplants are eight weeks old.
- Onions can be flamed for the first time when they are only 2 to 3 inches high.
- Cole crops can be flamed 2–3 weeks after transplanting.

Cross Flaming

Cross flaming is one of several methods that can be used to flame weeds in emerged crops. Burners are placed at an angle on either side of the row, in a staggered pattern so that the combined flames cover the entire drill row area. Setting burners directly opposite each other should be avoided, since this can create turbulence and cause flames to boil up and damage crop leaves.

During treatment, flames blow through the base of the crop, selectively killing weeds within the row without damaging the relatively heat-tolerant crop stems. Flames do not come in direct contact with crop foliage.

The specific flaming angle, flaming pattern, and flame length vary with the manufacturer's recommendations, but range from 30° to 40°, at 8 to 12 inches above the base of the plants, with flame lengths of approximately 12 to 15 inches. It is easiest to adjust the flame at night, when the flame path can be seen most clearly.

Some experimentation will be necessary to determine the appropriate ground speed for each crop and situation. Weed density, the age of the weeds, and weather conditions affect flaming results. Ground speeds can range from 3 to 5 miles per hour.

Photo courtesy of Dr. Wayne A. LePori, Department of Agricultural Engineering, Texas A&M

Parallel Flaming

Parallel flaming is a technique used to control weeds close to the rows for crops that are small or cannot tolerate cross-flaming. In this method, burners are set parallel to the direction of the crop row. A crop shield is sometimes employed to protect the crop.

Cross-flaming and parallel-flaming rigs are often combined with mechanical cultivators to control weeds between the rows. Mechanical implements may include tines, sweeps, or rolling cultivators.

Middle Flaming

A third method of post-emergent flaming is middle flaming. Two burners are installed under a lightweight hood that covers the row middles. The hood directs the flames to the weeds in the row middles while protecting the adjacent crop foliage.

Water-shielded Flaming

Water-shielded flaming is a technique that was developed for use on cotton farms in the Mississippi Delta. Water nozzles are placed on the flame rig to direct fans of water onto the crop plant for extra protection.

Infra-red Weed Control

Infra-red weeders—first developed in Europe—are heated by a propane torch, but the flame is directed toward a ceramic element or steel plate that radiates at temperatures of 1800 to 2000 °F. The danger associated with an open flame is thereby minimized. The mechanism of weed control is the same as in flame weeding; cell contents—plasma and proteins—are disrupted and the plant wilts down and dies. Infra-red heaters are available in hand-held, push-wheeled, and tractor-mounted models. In addition to weeding, the tractor-mounted infra-red thermal units are used to control Colorado potato beetle and potato vine desiccation. Some of the tractor models feature the injection of forced air to increase the effect.

In North America, a line of Swiss-made infra-red weeders are available through two companies: Forevergreen and Rittenhouse (see **Further Resources** below).

These range from hand-held to push-wheeled models suited to gardening, landscaping, nurseries, municipalities, and market farming. The hand-held and push-wheeled infra-red weeders appropriate for market farming are available in the $900 to $1,200 range. While infrared weeders appear to be a promising new thermal weed control tool, the equipment expense remains prohibitive for many smaller-scale market farmers. By comparison, a push-wheeled flame weeder is $300–$400.

Photo courtesy of Forevergreen

Steam + Hot Water Weed Control

Steam weed control and hot-water weed control have attracted attention in trade magazines, especially the fruit and vine grower magazines. High-temperature water provides a form of thermal weed control, yet eliminates the danger of flame application in arid regions where open fires are a hazard.

The January–March 2002 issue of *Weed Technology* featured a research article on steam application for cropland weeds (7). A custom-built, prototype steam generator-applicator machine with combined tillage implements was used in field trials. Weed control was comparable to glyphosate herbicide in some trials, and less spectacular in others. Factors affecting its use were: age of weeds, slow application speed, amount of steam applied, and cost of propane fuel. The authors concluded that improvements to steam equipment may make conservation tillage an option for organic farmers, by enabling no-till weed control without herbicides.

Altogether, the limiting factor to hot-water weed control is affordable small-scale equipment. There are three brands in North America: Waipuna, Aqua Heat, and Aquacide (See **Further Resources** below). However, they range in price from $9,000 to $35,000 and are primarily geared to municipal and institutional use for vegetation control around parks, lakes, and athletic fields, as well as non-cropland weed control around sidewalks, streets, and parking lots.

Practically speaking, innovative small-scale vegetable farmers are faced with scrapping together their own steam devices. Another option, perhaps, is collective ownership of equipment on a district-wide basis. Nevertheless, the technology exists and therefore it is mentioned here, along with equipment suppliers and web resources, for those growers who wish to investigate it further.

References

1) Anon. 1999. Flame weeding for weed management. The Practical Farmer [Practical Farm ers of Iowa]. Winter. p. 17.

2) Desvaux, R. and P. Ott. 1988. Introduction of thermic weed control in southeastern France. p. 479–482. In: Patricia Allen and Debra Van Dusen (eds.) Global Perspectives on Agroecology and Sustainable Agricultural Systems. Proceedings of the Sixth International Scientific Conference of IFOAM, UC-Santa Cruz, CA, Aug. 18–20, 1986.

3) Daar, Sheila. 1987. Update: flame weeding on European farms. The IPM Practitioner. March. p. 1–4.

4) Steve Meyer. March 2000. Personal communication.

5) Bowman, Greg (ed.) 1997. Steel in the Field: A Farmer's Guide to Weed Management Tools. Sustainable Agriculture Network, Handbook Series No. 2. Sustainable Agriculture Publica tions, University of Vermont. 128 p.

6) Janvanociski, Zlatko. 1999. Thermal infrared weed control. WA Bank Landcare Conference, “Where Community Counts,” Esperance, Australia. Accessed at: <http://www.wn.com.au/landcareconf/Javanociski.doc>.

7) Kolberg, Robert L., and Lori J. Wiles. 2002. Effect of steam application on cropland weeds. Weed Technology. Vol. 16, No. 1. p. 43–49. Accessed at: <http://www.bioone.org/bioone/?request=get-abstract&issn=0890-037X&volume=016&issue=01&page=0043>.

Further Resources

Equipment and Supplies

Flame Engineering, Inc.
P.O. Box 577
LaCrosse, KS 67548
888-388-6724
Fax: 785-222-3619
E-mail: flame@awav.net
http://www.flameengineering.com

Manufacturer of the famous Red Dragon hand-held flamer as well as alfalfa flamers, row-crop flamers (2 to 8-row kits), and a grape vine berm flamer that can also be used in orchards. A major supplier of liquid propane accessories to the flame weeding industry. See their online book, *Agricultural Flaming Guide*.

Thermal Weed Control Systems, Inc.
N1940 State Hwy 95
Neillsville, WI 54456
715-743-4163
Fax: 715-743-2921
Contact: Ron Jones
E-mail: jonesconsulting@juno.com

Manufacturer of row crop flamers (flame kits and complete units) that combine flamers for in-row weed control and rolling cultivators for between-row cultivation. Row-crop flaming kits are available for 4, 6, and 8 rows. A flame hood setup is also available.

LP Weed Burner
56360 200th Street
Wells, MN 56097
507-553-5633
Contact: Dennis Lutteke

Manufacturer of row crop flamers (flame kits and complete units) adaptable to cultivators or toolbars.

Peaceful Valley Farm Supply
P.O. Box 2209
Grass Valley, CA 95945
888-784-1722 Toll-Free
530-272-4769 Local
Fax: 530-272-4794
E-mail: contact@groworganic.com
http://www.groworganic.com

Organic farm equipment and supply dealer, carries: hand-held flamers, backpack frames for propane tanks, row crop flame kit suitable for mounting on a toolbar and flaming 4 rows.

Flame Weeders
Rt. 76, Box 28
Glenville, WV 26351
304-462-5589
Contact: Steve Myer
E-mail: flameweeders@juno.com
http://www.flameweeders.cjb.net

Farm-based equipment manufacturer specializing in flame weeders for market farmers. The flamers are mounted on wheels, combined with a flaming hood; the propane tank is carried on a back-pack frame. Models range in size from four torches at 24 inches in width to five torches at 30 inches in width, ranging in price from $300 to $400.

Forevergreen
19974 12 Avenue
Langley, BC
Canada V2Z 1W3
604-534-9326
Fax: 604-530-7129
E-mail: info@chemfree-weedcontrol.com
http://www.chemfree-weedcontrol.com

North American distributor of the Swiss-made Eco-Weeder, an infra-red thermal weeder heated by a propane flame passing over a ceramic casing. Models include hand-held and push-wheeled weeders for use around the home and in gardens, parks, market gardens, small farms, and orchards. Models: Punto Lady | Junior 3 Agri I / II | Agri Ronco | Agri IV 2 & 3 | Agri IV.

Rittenhouse & Sons
RR#3, 1402 Fourth Ave
St. Catharines ON, Canada
L2R 6P9
800-461-1041 Professional Sales
905-684-8122 Local
Fax: 905-684-1382
E-mail: prosales@rittenhouse.ca
http://www.rittenhouse.ca

See the section Alternatives for Weed & Pest Control. Rittenhouse sells the Infra-Weeder series in a price range of $210 for the hand held Infra-Weeder Eliminator (8.5 cm x 17cm plate), to $880 for the hand-held Infra-Weeder 100 (6" x 11" plate), to $1,200 for the push-wheeled Infra-Weeder 300 (8" x 12" plate).

Waipuna USA
1050 W. Lilycache
Bowlingbrook, IL 60440
630-514-0364
Fax: 630-759-8155
E-mail: jeffw@waipuna.com
Contact: Jeff Wingren
http://www.waipuna.com

Waipuna, from New Zealand, specializes in a hot foam system; the foam is derived from coconut sugar and corn sugar and is approved for organic production. A single-burner generator covers a width of 8 to 10 inches in the $22,000 price range. A double-burner generator covers a width of 24 to 32 inches in the $35,000 price range. Currently these are geared to municipalities, park departments, airports, and institutional settings. An agricultural unit is under development, with an aim toward orchards, vineyards, and similar agricultural applications.

Aqua Heat Technology, Inc.
5155 E. River Road, Suite 405
Minneapolis, MN 55421
763-785-2661
Contact: Harry Rajamannan

Aqua Heat is the company in Minnesota that developed hot-water weed-control equipment for orchards, vineyards, and park departments.

OESCO, Inc.
P.O. Box 540, Route 116
Conway, MA 01341
800-634-5557 Toll-Free
413-369-4335 Local
Fax: 413-369-4431
Email: info@oescoinc.com
http://www.oescoinc.com

Supplier of the Aquacide hot water weed control equipment system, in the price range of $9,000, geared to nursery production, landscapes, and park departments.

Videos

Vegetable Farmers and Their Weed-Control Machines is a 75-minute educational video on mechanical cultivation and flame weeding equipment produced in 1996 by Vern Grubinger (University of Vermont) and Mary Jane Else (University of Massachusetts), with funding from USDA-SARE. Cost is $12.00 from:

NRAES — Natural Resource, Agriculture, and Engineering Service
Cooperative Extension
152 Riley-Robb Hall
Ithaca, New York 14853-5701
607-255-7654
Fax: 607-254-8770
E-mail: nraes@cornell.edu
http://www.nraes.org/publications/sarev1.html

Web Resources

Thermal Weed Control: Flame Weeding

Flame Cultivation in Cotton
Mississippi State University Extension Service, IS 1500
http://msucares.com/pubs/is1500.htm

Flame weeding has a long history of use in the Mississippi Delta states. This fact sheet from Mississippi State University provides a brief introduction and summary on flame cultivation for cotton.

Flame Engineering, Inc. On-Line Agricultural Flaming Guide
http://www.flameeng.com/flamingg.htm

The Agricultural Flaming Guide provides a history of flame cultivation, with a summary of methods and flaming techniques for corn, soybeans, grain sorghum, cotton, potatoes, tomatoes, cole crops, alfalfa, and grape vineyards.

Other Practices to Control Weeds: Flame Weeding
Sustainable Practices for Vegetable Production in the South
Dr. Mary Peet, NCSU
http://www.cals.ncsu.edu/sustainable/peet/IPM/weeds/otherpra.html

Dr. Mary Peet published one of the very first books on sustainable vegetable production. This section touches on flame weeding, with a couple of farmer profiles.

Hot Tips For Flame Weeding
From: *Steel in the Field*, SAN Publications
http://wsare.usu.edu/docs/steel/p27-28.html

A section on flaming from *Steel in the Field*, a publication from SAN (Sustainable Agriculture Network). *Steel in the Field* is a practical handbook on non-chemical weed control, with very helpful diagrams and descriptions of 37 specialized cultivators used in mechanical weed control; highly recommended for the organic farmer's bookshelf.

Flame Weeding
Reducing Herbicide Usage on the Farm project | Agricultural Utilization Research Institute (AURI) and Sustainable Farming Association of Minnesota (SFA)
http://www.auri.org/proproj/flamewee.html

A report on flame weeding techniques and field trials on vegetable farms in Minnesota.

Flame Weeding for Weed Control and Renovation with Strawberries
Greenbook 2000, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture
http://www.mda.state.mn.us/ESAP/greenbook2000/FruitsWildung.pdf

Flame Weeding for Weed Control and Renovation with Strawberries
Greenbook 2001, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture
http://www.mda.state.mn.us/ESAP/greenbook2001/2001gb37.pdf

These two research reports summarize field trials on flame weeding for strawberries in Minnesota, with relevant details on weed control techniques and tips for flame weeding.

A Review of Non-Chemical Weed Control Techniques
S. Parish, Biological Agriculture and Horticulture, Vol. 7
http://www.eap.mcgill.ca/MagRack/BAH/BAH%205.htm

A reprint of a classic article in the journal *Biological Agriculture and Horticulture*, from one of the European researchers.

Thermal Weed Control by Flaming: Biological and Technical Aspects
J. Ascard. Department of Crop Production Science, Swedish University of Agricultural Sciences, Uppsala, Sweden
http://zeus.bibul.slu.se/documents/slu/rapport_lantbruksteknik/RLT200/RLT200.HTM

A detailed and informative summary of flame weeding research, apparently an abbreviated version of J. Ascard's thesis through Swedish University of Agricultural Sciences (a 43-page printout).

Comparison of Three Weed Control Methods: Chemical, Flame and Hot Water
University of Queensland (Australia)
http://life.csu.edu.au/agronomy/papers/315/315.html

Hot water was as effective as glyphosate herbicide. Flaming was less effective, but acceptable weed kill was obtained on juvenile weeds.

Great Balls of Fire!
Ecological Farmers Association of Ontario
http://eap.mcgill.ca/MagRack/EFA/EF_95_P_05.htm

A brief report on field trials regarding flame weeding in potato production.

Flame Weeding in the Garden
By Sheila Daar
http://www.gameco.com.au/Flame%20Weeding.htm

An online reprint of The IPM Practitioner article by Sheila Daar, located on the Gameco gas equipment company site in Australia.

Controlling Weeds in Organic Crops Through the Use of Flame Weeders
Ronnie W. Heiniger. Organic Farming Research Foundation. No. 6. Summer. p. 17–19.
http://www.ofrf.org/publications/news/ib6.PDF

A research report from the Organic Farming Research Foundation. The project took place in North Carolina and investigated the use of flame equipment in organic popcorn, soybeans, and cotton. The complete 11-page report is available from OFRF and includes tables with economic cost, gas usage figures based on pressure and tractor speed, and weed biomass and yield figures for popcorn.

Flame Weeding Research at Texas A&M
Dr. Wayne A. LePori, Department of Agricultural Engineering,Texas A&M University
http://baen.tamu.edu/users/lepori/Research/Flame/flame_weeding.htm

Dr. Wayne LePori's flame weeding research program at Texas A&M, in collaboration with Mississippi State University and University of Florida, is aimed at developing new burner designs and equipment modifications for improved flame weeding in cotton, sugar cane, vegetables, and other crops. This site features quarterly research reports and slide presentations, available as downloads, with color photos of equipment, field trials, and research results.

Flame Weeding Research at Nova Scotia Agricultural College | Nabil Rafai
http://www.nsac.ns.ca/eng/staff/nri/

Dr. Nabil Rafai's research site provides results and photos of flame weeding and steam weeding.

Thermal Weed Control:
Infra-Red, Steam, Hot Water, International Companies & Technology

Controlling Weeds Using Propane Generated Flame or Steam Treatments in Crop and Non-Croplands
Dr. Thaddeus Gourd, Adams County, Colorado State University Cooperative Extension
http://www.colostate.edu/Depts/CoopExt/Adams/ag/swcg2002.htm

Colorado State University will compare flame and steam weed control methods and equipment, including the Atarus Stinger.

The Use of Steam as an Alternative Herbicide
Sandra Robinson, Virginia Tech
http://fbox.vt.edu:10021/S/sarobins/robinson.htm
http://fbox.vt.edu:10021/S/sarobins/robinsn2.htm

Reviews the use of the Aqua Heat hot-water weed control system, with a summary of the advantages and disadvantages.

Hot Water Weed Control in Carrboro, NC
http://ftp.oit.unc.edu/arc/waipuna.htm

The Waipuna hot-water weed control system is being used by the Town of Carrboro, North Carolina, as part of its Least Toxic Integrated Pest Management (IPM) policy and pesticide reduction program that seeks least-toxic alternatives.

Hot Water: A "Cool" New Weed Control Method
Journal of Pesticide Reform. Vol. 15, No. 1.
http://www.eap.mcgill.ca/MagRack/JPR/JPR_27.htm

Reprint of a brief article introducing the hot-water weed control method, featuring the Waipuna system from New Zealand.

Effect of Steam Application on Cropland Weeds
Kolbert, Robert L. and Lori J. Wiles. 2002. | Weed Technology. Vol. 16, No. 1. pp. 43–49.
http://www.bioone.org/bioone/?request=get-abstract&issn=0890-037X&volume=016&issue=01&page=0043

Journal article in *Weed Technology*, summarizing research on a custom-built, prototype steam generator-applicator machine with combined tillage implements for use in row crop weed control and no-till agriculture.

Hot Water Technology
EPA Methyl Bromide Alternatives
http://www.epa.gov/Ozone/mbr/casestudies/volume1/aquaheat.html

A case study on field trials with the Aqua Heat system in Florida, aiming to control nematodes and soil-borne pathogens. Custom applicator costs are estimated at $1,000 to $1,500 per acre for hot water, which is comparable to $1,200 to $1,500 per acre for methyl bromide.

Nursery Soil Fumigation
Dick Karsky, National Proceedings: Forest and Conservation Nursery Associations, 1997
http://www.na.fs.fed.us/spfo/rngr/pubs/np97/fumig.htm

A paper on steam for soil fumigation in field-grown nursery production. This item is included for the notes, photos, and comments on steam technology and equipment in general.

Eco-Weeder (Puzzy Boy)
The Nature Conservancy newsletter
http://tncweeds.ucdavis.edu/tools/puzzy.html

A newsletter about the Swiss-made infra-red eco-weeder from Forevergreen, also known in Europe as the Puzzy Boy.

Bare Ground Control Alternative: Flamers and Steamers
Model Pesticide Reduction Plan, Air Force Center for Environmental Excellence
http://www.denix.osd.mil/denix/Public/Library/AF_P2/Pest/app_b.html

A report on IPM weed control from the Air Force. It reviews the use of flamers and steamers for weed control, with cost estimates and pros and cons.

Thermal Treatment in Agriculture
Primagaz Ltd. (Hungary)
http://www.primagaz.hu/pages/mezogazdasagi/mezogazdasagi.en.html

Manual Thermal Weed Control
http://www.primagaz.hu/pages/mezogazdasagi/kezigyomirtok.en.html

The Heat Sensitivity of Weed Types
http://www.primagaz.hu/pages/mezogazdasagi/gyomokhoerzekenysege.en.html

Weeds are categorized into three levels of heat sensitivity: Highly, Moderately, and Slightly Sensitive to flame weeding.

Atarus Thermal Weed Control (Australia)
http://www.atarus.com.au/thermal.htm

The Atarus Stinger features a technology known as water-quenched combustion—a generator that con verts combusting fuel and water into a high-velocity, high-temperature, moist air flow. It is geared to orchards, vineyards, and row crops. The Atarus Ranger is a hand-held flame torch for use on farms, parks, and other landscapes.

Weed Control | HOAF Group | InfraRed Technology (The Netherlands)
http://www.hoaf.nl/Engels/html/en-onkruid.htm

Greenburner: Potato desiccation | HOAF Group | InfraRed Technology
http://www.hoaf.nl/Engels/html/en-lb_30.htm

Test Results with Greenburner| HOAF Group | InfraRed Technology
http://www.hoaf.nl/Engels/html/en-lb%20bv-expl.htm

The Drackedon Greenburner (UK)
http://www.drackedon.co.uk/prod_en.htm

Potato Haulm Destruction: The Alternative Methods and their Environmental Impacts
Mike Denbigh, student paper, Wye College, July 1997
http://www.drackedon.co.uk/docs_md1_en.htm

Thermal Infrared Weed Control
Zlatko Janvanociski. 1999. WA Bank Landcare Conference, "Where Community Counts," Esperance, Australia
http://www.wn.com.au/landcareconf/Javanociski.doc
A 4-page report from Australia.

ISHS Acta Horticulturae 372: Symposium on Engineering as a Tool to Reduce Pesticide Consumption and Operator Hazards in Horticulture
http://www.actahort.org/books/372/
Symposium abstracts, including a number of papers on thermal weed control.

Puzzy Boy Unkrautvernichter
http://bruehwiler.com/puzzyboy.htm
Web page for a German company selling the Puzzy Boy line of infra-red weeders. The pictures are a fast way to grasp what the different models look like.

UV Weed Control
Kaj Jensen and Electro Light ApS
http://www.kaj.dk/weed-by-uv.htm
Weed Control by ultraviolet (UV) light using high-powered electronic ballasts.

By Steve Diver
NCAT Agriculture Specialist

Edited by Richard Earles
Formatted by Ashley Hill

June 2002

CT165

The electronic version of **Flame Weeding for Vegetable Crops** is located at:
HTML
www.attra.ncat.org/attra-pub/flameweedveg.html
PDF
www.attra.ncat.org/attra-pub/PDF/flameweedveg.pdf

Michigan State University Extension Bulletin E-3038 • New • January 2008

Flaming as a Method of Weed Control in Organic Farming Systems

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Introduction

Using fire to control weeds in organic farming systems shows promise for reducing weed populations without herbicides. A carefully directed flame fueled by natural gas or liquid propane (LP) increases the temperature within the weed, causing cells to rupture and effectively killing weeds while doing little damage to the crop (Fig. 1). Flaming disrupts weed growth through heat, so it is important to flame when the plants are dry and wind speed and direction are favorable. Both moisture and wind can lower the heat from the flame, reducing the effectiveness of the flaming application (Mutch et al., 2005).

Weeds are most susceptible to flame heat when they are 1 to 2 inches tall or in the three- to five-leaf stage (Sullivan, 2001). Broadleaf weeds are more susceptible to flaming than grasses such as foxtail.

Fig. 1. Organic corn that has been flamed for weed control. Flaming kills weeds while doing little damage to the crop.

For many grasses, the growing point is below the soil surface where the flame's heat cannot penetrate effectively to stop or suppress growth.

Some farmers have found that flaming controls certain weeds (lambsquarters and pigweed, for example) better than others (mustards or common ragweed) (Mutch et al., 2005). Flaming is more effective in a crop such as corn, where the growing point is below the soil surface, than in crops such as soybeans, where the growing point is aboveground. The authors of this bulletin do not recommend using flaming to control weeds in soybeans.

Exposing a weed seedling to flame for 1/10 of a second (Row Crop, 2007) is usually enough to ensure control, although this may vary with weed type and size (Fig. 2). Smaller, sensitive plants are more susceptible to heat than larger, more mature plants. Applying the flame when the crop plants are larger than the weeds provides for optimal control. After an effective flame application, weed leaves look dull, and it is easy to press a visible fingerprint onto the leaf surface.

Fig. 2. Closeup view of burned common lambsquarters in the corn row. The burned corn leaves did not result in a reduced corn yield because the corn's growing point is below the ground.

Methods and research

A Michigan State University W.K. Kellogg Biological Station (KBS) study examined the effectiveness of postemergence weed control by cross-flaming (Fig. 3). Cross-flaming burners are set at an angle 30 to 60 degrees from horizontal and 4 to 10 inches away from and perpendicular to the crop. Gas pressures are typically operated between 25 and 70 pounds per square inch (PSI).

Fig. 3. Cross-flaming in organic corn. In this system of flaming, the torches are generally staggered while flaming so that each does not interfere with the flame from the opposite burner.

Torches are staggered to limit interference between flames. This allows the heat to be directed into the crop from both sides. This provides more complete coverage and allows for greater application speeds, ranging between 2.5 and 5 mph. In general, flame application LP gas usage averages 8 to 10 gallons per acre, depending on application speed (Sullivan, 2001).

The two-year KBS study evaluated the effectiveness of flaming by comparing three treatments (Table 1) for weed control in organic corn systems. The treatments used were flaming, rotary hoeing (Fig. 4), and rescue treatments for early- and late-planted corn. Rescue treatments were late-season flaming when prior weed control measures had not been undertaken. All treatments were cultivated as needed in addition to the weed control treatments under evaluation.

Table 1. Weed control treatments.

Trt	Weed control
1	Rotary hoe as needed, cultivate
2	Flame as needed, cultivate
3	Rescue, late flaming, cultivate

The three weed control treatments were evaluated each year in early- and late-planted corn. Prior to planting, plots were tilled three times using the methods given in Table 2 as required to provide consistent seed beds.

Table 2. Preplant tillage.

Pass	Tillage method
1	Chisel plow or field cultivator
2	Disk or field cultivator
3	Field cultivator

The three treatments were applied to corn planted early and late in a randomized complete block design with three replications. In 2005, early and late planting occurred on May 6 and May 18, respectively. In 2006, early planting occurred on May 8 and late planting on May 23.

Results

Figures 5 and 6 summarize the timing, treatments, weed control operations, mean yield and weekly precipitation for the three treatments of early- and late-planted corn in 2005 and 2006.

There was no significant difference (at $p < 0.025$) in corn yield between years, when averaged over planting dates and years. However, the yield of late-planted corn in 2006 was significantly higher than the yields of early-planted corn. There was no difference in corn yield between early- and late-planted corn in 2005.

Figure 7 shows the results of the weed control treatments by planting date and year. In general, the results of flaming and rotary hoeing were not different from each other with the exception of the late-planted corn in 2005. The yields resulting from rescue treatments in 2005 were not different from those of the rotary hoeing and flaming except in late-planted corn in 2005. The yields resulting from rescue treatments in 2006 were different from rotary hoeing and flaming within respective plant dates but were not different from rotary hoeing or flaming for other planting dates.

Fig. 4. Rotary hoeing weeds in organic corn.

Discussion:

2005 crop season

In 2005, the total precipitation from April through October was 15.5 inches. As shown in Figure 5, the spring prior to both the early and late planting dates was dry, as was the period from late July to early September. This lack of moisture resulted in reduced weed emergence. All three weed control treatments provided similar weed control under these dry growing conditions. However, corn that was flamed late in 2005 had a lower yield than corn with all other 2005 treatments except early rotary hoeing. Late flaming under the dry conditions may have led to some incidental damage to the corn crop. The reduced number of weed control operations (three versus four or five) appears to provide an advantage for the rescue treatment under dry growing conditions.

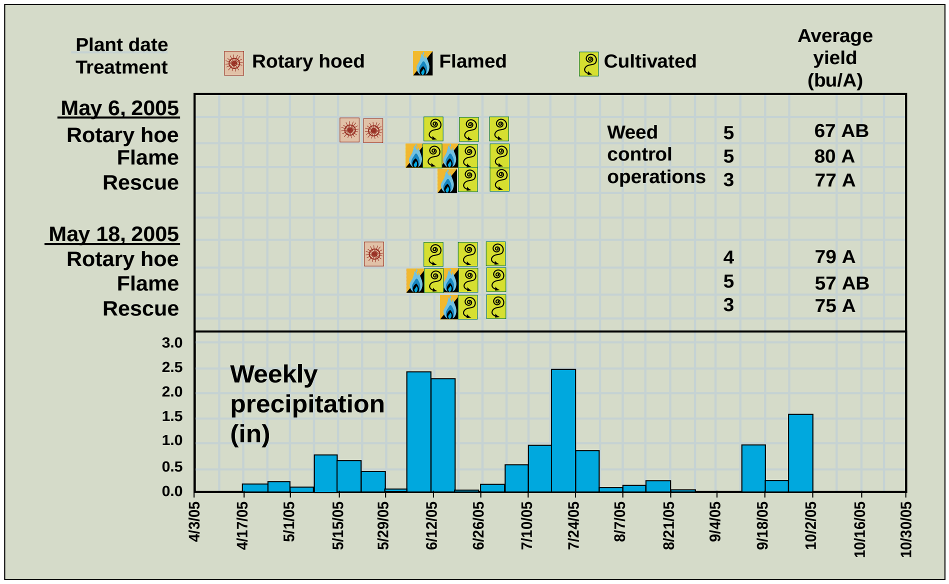

Fig. 5. Summary of 2005 weed control treatments (means with the same letter are not significantly different at the p < 0.025 level; LSD @ 0.025 = 10.7).

2006 crop season

In 2006, there were no statistical differences between mean yields for corn treated by flaming and rotary hoeing within planting dates. Rescue mean yields were statistically different from both flaming and rotary hoe corn yields at each planting date. The mean yields under the rescue treatments were 25 to 30 bushels per acre less than the yields of corn receiving the rotary hoe and flame treatments. In 2006, the total precipitation from April through October was 27.7 inches and evenly distributed through the growing season (Fig. 6). With adequate moisture, the advantage of early weed removal is evident in the increased yields for the flame and rotary hoe treatments versus the rescue treatment.

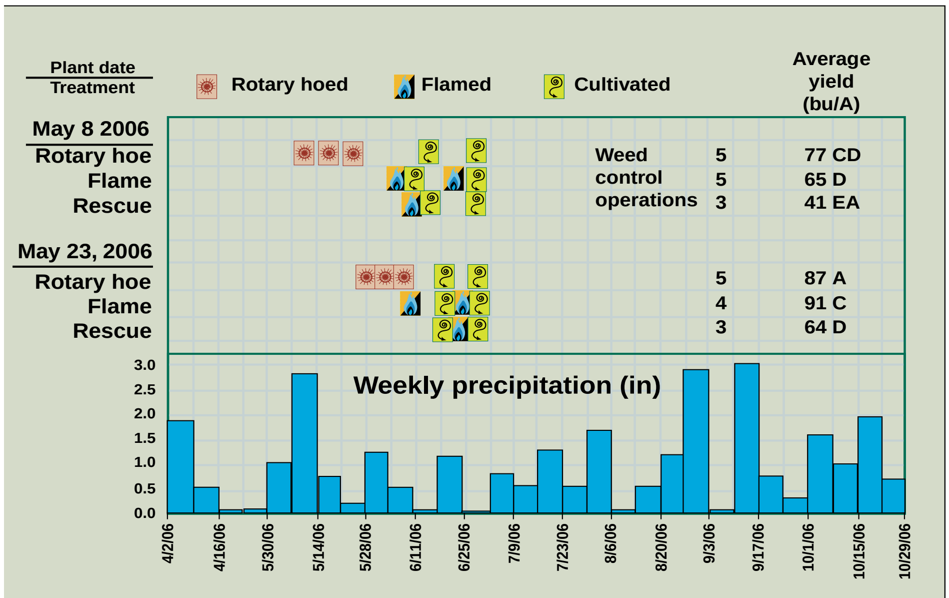

Fig. 6. Summary of 2006 weed control treatments (means with the same letter are not significantly different at the p < 0.025 level; LSD @ 0.025 = 16.5).

Combined 2005 and 2006 crop seasons

Combining data from 2005 and 2006 shows the same trends observed in the individual years. Early and late planting dates mean yields (76 and 68 bushels per acre, respectively) statistically differed by 8 bushels per acre (LSD @ 0.025 = 7). Overall, the mean yield for the flame treatment at 73 bushels per acre was not statistically different from that of the rotary hoe treatment at 77 bushels per acre. However, mean yield for the rescue treatment at 65 bushels per acre was less than the yield in the rotary hoe and flame treatments at the p < 0.025 level.

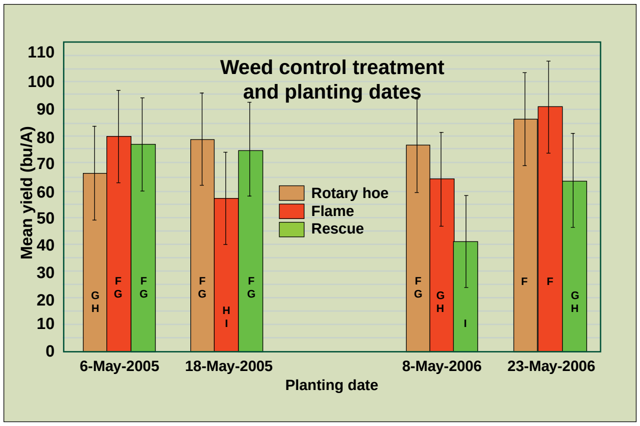

Fig. 7. Weed control treatment effects including year and planting date interactions (means with the same letter are not significantly different at the p < 0.025 level; LSD @ 0.025 = 16.5).

Conclusions

On a well-drained sandy loam soil, corn yields were similar when weeds were controlled with rotary hoeing or flaming treatments (Figure 7). Corn yield was reduced when late "rescue" weed control was attempted in wetter years.

Flaming offers a number of advantages over the more widely used organic weed control practice of rotary hoeing. Rotary hoeing can be impractical in shallow or dense claypan soils; flames can be applied in systems with any soil type or depth. Rotary hoeing also depends on dry soil conditions; flame application is not as affected by weather variability. Flaming is also less invasive, preserving soil structure and leaving crop roots unharmed.

Though there are many benefits to applying flames to control weeds in organic systems, there are also downsides. Optimal weed control often requires multiple flame applications, with little or no residual weed control effects. Flame applications must be timed precisely to effectively kill weeds, and weeds that emerge with the crop are particularly difficult to control without damaging the crop.

The rising cost of propane gas is another factor to consider when deciding whether to add flaming to a weed management system. Conducting a cost/benefit analysis is important to see if flaming is a financially viable option for an individual operation.

There are many considerations to take into account when deciding whether to use flaming as a weed control practice in any farming system. Farmers should carefully evaluate the positives and the negatives before integrating a flame-applied weed control approach into their operations.

Acknowledgements

The authors would like to thank Karen A. Renner and Christy L. Sprague for their invaluable comments in the review of this bulletin.

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MICHIGAN STATE UNIVERSITY EXTENSION

Miscellaneous

Weed Control Strategy Differences in Alternative/Organic vs. Conventional Farming (Rutgers)

Low-Input Management of Weeds in Vegetable Fields (California Agriculture)

Monthly Highlights from Rutgers New Jersey Agricultural Experiment Station January 2009

Weed Control Strategy Differences in Alternative/Organic vs. Conventional Farming

Brad Majek, Specialist in Weed Science and Jack Rabin, Associate Director - Farm Programs

Let no weeds go to seeds. Farmers wanting to control weeds with non-chemical herbicide alternatives should not underestimate their challenge. There is a conflict between the goals of improving soil health and achieving weed control sufficient for viable crop yields and profitable farming. Table 1 provides a glimpse at the changes in farmers' time and effort required for alternative management.

Farming without herbicides on mid-Atlantic Coastal Plain soils (coarse and sandy) pushes farmers in opposing directions. Farmers forego building soil quality with aggressive mechanical tillage and cultivation sufficient for controlling weeds. These practices decrease (oxidize) soil organic matter and reduce tilth. Alternatively, farmers can implement multi-year rotations, including fallow and cover crops, but significantly impair their cash crop selection and profits in order to simultaneously control weeds and improve soils. Both goals can be pursued, but remain a challenge demanding more manager time, intensity, creativity, and compromises based on personal farming goals.

Most sustainable farms integrate ***all*** mechanical, cultural, and chemical controls available, minimizing inputs. Moreover, cultural weed controls, like those used in conservation tillage, depend upon mechanical tillage and chemical support. Upon removing chemical controls in alternative/organic farming, we become solely dependent on cultural and mechanical methods, which dramatically

Top: *With a rotary hoe, Jesse Smith runs shallow, over dry soil, just prior to crop emergence, at high speed on organic fields. Timing and soil conditions are critical to achieve soil "flail," removing emerged weed seedlings without undue crop damage.*

Bottom: *Close-up of tines on Yetter rotary hoe we purchased used. Popular as a "steel in the field" herbicide alternative for pre-emergence and early post-emergence weed control.*

Continued on page 2

Table 1. Role of weeds in managing the farm enterprise

Alternative	Conventional
Controlling ***weeds much more important*** part of farm enterprise.	Controlling weeds less important part of farm enterprise.
Weeds a much ***higher management priority.*** A top farming priority becomes not permitting weeds to go to seed.	Weeds a lower management priority.
More ***time and money*** managing and performing weed control tasks.	Less time and money in weed control tasks.
Timing of weed control practices very critical.	Timing of practices less critical.
As the farmer, you decide where your time is most valuable. How will important farm tasks change due to weed control?	

Left: *In organic field corn at the Rutgers Agricultural Research and Extension Center farm, Pigweed and Ragweed escaped because we missed cultivating at a critical time period. USDA Northeast Sustainable Research and Extension (SARE) fund on-farm alternatives training to meet these challenges.* **Right:** *Using wider row soybeans and rotary hoe just prior to emergence, followed by precisely timed aggressive cultivation based on "footprints in the field" crop observance, our organic soybean fields were freer from weed competition.*

elevate weed control on already burdened farm managers. We replace chemical use with increased management hours and intensity. It can be successfully achieved. Not all farmers want to devote increased management time to weed control, but successful organic farmers are obligated to this path. It becomes part of their passion on the farm.

When practicing even the best alternative/organic weed management strategies, be aware that just as in the 1920s-1950s mechanized but pre-herbicide era, about 25% of crop seedings will regularly suffer reduced yields or fail due to weed competition. Intermittent rainfall and lack of supplemental irrigation remain an equally important additional cause of crop seeding failures.

Farmers pursuing herbicide alternatives, organic farmers, or beginning and part-time farmers cannot underestimate the ***time and timing*** challenges faced when pursuing soil health, weed control, mechanical tillage, sufficient cash crop acres, manageable farming intensity, and sustainability. Table 2 provides guidance on modifying crop production strategies, practices, and compromises for alternative weed control. In the tension between building soil quality and weed management, there is no free lunch, and there never were any good 'ole days. Organic farmer surveys repeatedly reveal weed control failures among their priority production problems.

Options meeting these challenges on coarse Coastal Plain soils emerge from grower experiences and joint efforts by Rutgers NJAES and NRCS USDA. Farmers incorporating municipal leaves, shredded construction or pallet wood, spent mushroom compost, animal manure, or any clean community waste carbon sources can improve soil organic matter far better than cover crops alone, while still performing increased mechanical tillage weed control alternatives. In summary, farmers have four weed control methods in their toolbox:

Mechanical. All common tillage practices before and after planting crops, including frequent cultivation at precise times using specialized implements, deep plowing to bury weed seed banks, etc.

Cultural. Includes fallowing land, stale seedbeds, adjusting seeding dates, transplanting instead of seeding, mowing, and smother cover crops, etc.

Chemical. Chemical weed control reduces human drudgery and suffering from back breaking hoeing labor, reduces fuel use and energy inputs, and helps build soil quality by reducing tillage when integrated with other practices. Conservation minimum-till and no-till practices benefit soil and water quality on millions of acres, yet abso-

Continued on page 3

lutely depend on chemical herbicide control integrated with cultural control and large implements, "steel in the field."

Biological. Historically not deployed in intensive farming systems. Successes include rangelands, pastures, and against invasive weeds on non-cultivated land. E.g., in New Jersey, beneficial insect releases have combated Purple Loosestrife, and Canada Thistle and Musk Thistle in permanent animal pastures.

The challenge remains integrating their use grow profitable crops and improve soil health at the same time.

Table 2. Strategies for Field & Forage crops

Alternative	Conventional
Fallow fields up to 6 months. Particularly for thistle and nutsedge problems. Till every 7-10 days in weed critical periods. Fuel use and costs increase.	Crop every year. Use cover crops between seasons.
Plant competitive cover crops like Sudax, buckwheat, or alfalfa on stale seedbeds.	Crop every year. Use cover crops between seasons.
Stale seedbeds with later optimum planting dates. Fuel use and costs increase.	Earliest optimum planting dates.
Mow several times.	Post emergence herbicide @ 10 weeks +/-.
Fertilize post planting, only after viable establishment has been determined (or not). Late fall.	Preplant broadcast fertilization and post plant fertilization.
Maximum *plus* high seeding rates. Higher plant populations to competitively overwhelm weed seedling populations and withstand rotary hoe.	Minimum recommended seeding rates. Saves seed and/or encourages using expensive, but higher performing varieties.
Be prepared to replant 25% of seedings. This is independent of irrigation.	Expect successful stand establishment.
Strategies for annual field or horticulture row crops	
Alternative	**Conventional**
Limit (reduce) cropped acreage. Achieve time and timing for performing effective of weed control tasks.	Increase acreage and limit time. Use time for management tasks like sales, supervising labor, etc.
Greater impact of field rotations on cash crop selection. Increase length of rotations out of crops competing poorly against weeds. Increase fallowing, only grow your most desired cash crops 1-2 years out of 5, add field and forage crop rotations to high value horticulture crop farms, etc.	Less impact of crop rotations on selecting most desired cash crops. Increase use of cover crops between seasons.
Stale seedbed preparation. Start earlier, use more tillage, and plant later. Fuel use and costs increase. Equipment use and costs increase.	Make multiple plantings.
Open-pollinated seed use.	Hybrid seed use.
No broadcast or banded preplant fertilization. Sidedress only.	Broadcast preplant and sidedress fertilization.
Wider rows. Increases amount of soil cultivated in fields.	Narrower rows. Reduces amount of soil cultivated.
Increase "in-row" plant populations. Assists emergence in some soils. Risk with corn of within-row competition.	Reduce "in-row" plant population.
Determine competitive viability at 3 week +/- critical stage between young crop and weed seedlings. Prepare to replant ¼ to 1/3 seedings.	All seedings succeed.
Transplant hybrids of high value crops.	Direct seed hybrid crops.

Courtesy of SAFS project

Jack Kelly Clark

An in-row cultivator uproots weeds in the organic corn plots. The torsion rods loosen soil in the crop row, dislodging small weeds without injury to the deep-rooted corn crop.

In low-input and organic systems . . .

Researchers find short-term insect problems, long-term weed problems

W. Thomas Lanini ❑ Frank Zalom ❑ James Marois ❑ Howard Ferris

The conversion from conventional to low-input or organic crop production requires changes in pest control tactics. In a 5-year study, abundance of most pests did not change dramatically between conventional and low-input or organically managed systems, with a few notable exceptions. Organic and low-input plots suffered significantly greater damage from tomato fruitworm in 1989 and stink bugs in 1992. The major long-term effect has been on weeds. Weed control methods differ among the systems and have resulted in more barnyardgrass in low-input and organic systems and field bindweed and nightshade in conventional systems.

Increasing numbers of growers are considering changing from conventional to low-input or organic farming systems as political, economic and biological pressures increase. A major obstacle in making this transition has been a lack of information on pest biology, occasional outbreaks of unexpected pests that are difficult to manage with organic practices and lack of economic, nonchemical control options for some pest species.

The crop being grown, cultural practices used in that crop, prior cropping history, neighboring crops and pest control methods employed all influence pest species' abundance and composition. Each crop typically attracts its own subset of pest species. For example, both corn and tomatoes are attacked by cutworms and wireworms, but only corn is attacked by corn smut, and only tomato by black mold. The subset of pests affecting a certain crop may be limited by the time period in which that crop is grown; for example, processing tomatoes are generally planted earlier than corn and may be impacted by a different species guild at that time. However, since the crop affects pest species and abundance, the first crop in a rotation can also influence the entire rotation by increasing the weed seed, insect and plant parasitic nematode populations or inoculum level of pests and pathogens common to subsequent crops as well.

Cultural practices used in a crop or cropping system also can influence pest populations. For example, legume cover crops are beneficial in providing nitrogen for the succeeding cash crop, but they also modify the microenvironment, potentially influencing pest populations. Seed corn maggot populations may be enhanced with increased moisture and humidity associated with a winter cover crop, while frequent tillage or host-free periods reduce their abundance. Cover crops require incorporation prior to planting of the subsequent crop. This may result in changes in crop planting time, potentially exposing the crop to a different subset of pests.

Pest control methods used in different farming systems vary in their effectiveness and in the range of species they control. Tillage, used more frequently in low-input and organic farming systems, favors annual weeds capable of reproducing in a short period of time or perennials that regrow after tillage and benefit from reduced competition. Frequent tillage also helps to spread weed seed, perennial vegetative propagules and disease inoculum. Herbicides or insecticides vary in effectiveness between species, allowing those not controlled to proliferate. This effect is especially pronounced when the same material is used repeatedly and can also lead to pest resistance.

The shift from conventional to low-input or organic farming systems necessitates the modification of cultural practices and pest control methods. Although it is recognized that pest populations will change in this transition, the species composition, diversity and abundance that result are not known. In this long-term study, the Sustainable Agriculture Farming Systems project at UC Davis, four farming systems were compared. Each system differed in the cultural practices and pest control methods used. The objectives of this study with regard to pest biology and management were to assess, over time, the relative abundance and species composition of pests in each of the four farming systems. Additionally, practical cultural modifications implemented in low-input or organic systems were compared to assess their influence on pests.

Monitoring practices

The cropping systems were established in 1989 (for details, see pp. 14–19). Individual plots were approximately one-third acre in size and replicated four times. All systems were managed using "best farmer practices" recommended by farmers and farm advisors who were members of the project team. Management decisions were based on cost of control, potential loss and environmental or social implications appropriate to the system (see tables 1 and 2). Pest monitoring and treatment decisions were made according to the UC Integrated Pest Management Project (IPM) guidelines. California Certified Organic Farmer (CCOF) guidelines were adhered to in the organic plots. Low-input treatments used a combination of CCOF and UC IPM guidelines, attempting to reduce off-farm inputs.

Insect monitoring varied by crop. Processing tomato seedlings were monitored for evidence of feeding by flea beetles, cutworms and wireworms by recording the number of damaged plants per 25 consecutive plants in the third row of each treatment replicate border. After small green fruit appeared, we picked 30 leaves (the leaf below the highest open flower) per plot, and counted the number of fruitworm eggs, parasitized eggs and leaves with potato aphids and parasitized aphids. Each week after green tomatoes reached 1 inch in diameter, we randomly picked 50 tomato fruit per plot and examined them for fruitworm damage.

Also at this time, we examined the base of the plants and lower leaves for bronzing by russet mites and applied sulfur treatments if mite damage was detected. To determine the presence of stink bugs, we placed trays below the foliage of three tomato plants and shook the plants. The trays and the areas under the trays were then examined for stink bugs

Seedling corn was visually examined for signs of feeding by seed corn maggots, cutworms and wireworms. Spider mites and aphids were monitored by picking 40 lower leaves (not senescing) per plot every 2 weeks and recording the number of leaves with spider mites, mite predators, aphids and parasitized aphids. Once tassels and silk were present, the number of ears with corn earworm were recorded each week until the dent stage.

In beans, safflower and wheat, insects were not monitored on a regular basis. The plots were examined for the presence of arthropods after seedling emergence. More intensive monitoring was conducted when pest presence was detected.

We made an annual inventory of all nematode species present and the populations of each species in each plot. Soil samples were taken to a depth of 30 centimeters, with 20 to 30 soil cores pooled in each plot. Nematodes were extracted from a 300- to 400-cm^3 subsample of soil by elutriation and sugar centrifugation. For each sample, the total number of nematodes was counted and a subset of 200 to 300 individuals identified by genus (and species where possible). The number of each nematode type per liter of soil was calculated for each plot. The species of nematodes were categorized according to their feeding habits.

Plant diseases were visually evaluated in each plot weekly. Detailed assessments of Rhizoctonia and Verticillium presence in soil samples were made yearly.

Weed cover was visually assessed on each plot monthly, with predominant weed species noted. Measurements were generally made just prior to cultivation or herbicide treatment. Biomass measurements were made in each plot at crop harvest by clipping all weeds at ground level in a randomly placed 0.25-m^2 quadrat. We generally took four biomass samples per plot, and never less than two. Biomass samples were separated by species, dried and weighed.

Control treatments

Insects. As might be anticipated, little difference in abundance of highly mobile pests was seen among systems (table 3), as the relatively small plots allowed migration between plots. With only a few exceptions, most differences between systems appeared to be due to treatments applied for control. There were differences in abundance of some species across all treatments between years.

In processing tomatoes, an application of sulfur (Thiolux) was applied to all plots in the 1989, 1990 and 1991 sea-

TABLE 1. Pest management and inputs per acre for alternative systems*

		Organic and low input†	Conventional 2- and 4-Year
WEEDS			
Tomato	1989	Cultivate‡ — 8X Hand hoe — 3X (22.2 hours)	Cultivate — 8X Hand hoe — 3X (14.8 hours) Preplant Devrinol @ 0.2 gal Layby Treflan @ 1.45 pint
	1990	Cultivate — 6X Hand hoe — 2X (43.9 hours)	Cultivate — 4X Hand hoe — 2X (7.4 hours) Preplant Devrinol @ 0.2 gal Layby Treflan @ 1 pint
	1991	Cultivate — 7X Hand hoe — 3X (64.5 hours)	Cultivate — 4X Hand hoe — 3X (21.5 hours) Preplant Roundup @ 1.5 pint Preplant Devrinol @ 0.2 gal Layby Treflan @ 1 pint
	1992	Cultivate — 3X Hand hoe — 3X (**O:** 32.0 hours, **LI:** 28.0 hours)	Cultivate — 3X Hand hoe — 3X (10.4 hours) Fallow Roundup @ 1.7 pint Preplant Devrinol @ 0.36 pint
Safflower	1989	Cultivate — (**O**:4X **LI**: 5X) **LI only:** Fallow Roundup @ 1.5 pint	Cultivate — 4X Fallow Roundup @ 1.5 pint Preplant Treflan @ 1.5 pint
	1990	Cultivate — 1X	Cultivate — 2X Fallow Roundup @ 1.3 pint Preplant Treflan @ 1.4 pint
	1991	Cultivate — 1X	Cultivate — 1X Fallow Roundup @ 1.5 pint Preplant Treflan @ 1.5 pint
	1992§	Cultivate — 7X Mow weeds — 2X	Cultivate — 1X Fallow Roundup @ 1.7 pint Preplant Treflan @ 1.5 pint
Corn	1989	Cultivate — (**O**:4X **LI**: 3X) **LI only:** Fallow Roundup @ 1.5 pint Mow weeds — 1X **LI only:** Layby Weedar @ 1 pint & Banvel @ 0.5 pint	Cultivate — 5X Fallow Roundup @ 1.5 pint Mow weeds — 1X Layby Weedar @ 1 pint & Banvel @ 0.5 pint Preplant Dual @ 2 pint
	1990	Cultivate — 1X Layby Weedar @ 1 pint & Banvel @ 0.5 pint	Cultivate — 1X Layby Weedar @ 1 pint Fallow Roundup @ 1.5 pint Preplant Dual @ 2 pint
	1991	Cultivate — 1X	Cultivate — 1X Fallow Roundup @ 1.5 pint Preplant Dual @ 2 pint
	1992	Cultivate — 3X **LI only :** Layby Weedar @ 2 pint	Cultivate — 1X Fallow Roundup @ 1.7 pint Preplant Dual @ 2.5 pint
Winter legume/ wheat	1989	Cultivate — (**O**:4X **LI**: 1X) **LI only:** Preplant Dual @ 2 pint & Prowl @ 2 pint	Postplant Bronate @ 2 pint
	1990	—	Postplant Bronate @ 2 pint
	1991	—	Postplant Bronate @ 2 pint
	1992	—	Postplant Hoelon @ 1 pint & MCPA @ 1 pint
Beans¶	1990	Cultivate — 1X	Cultivate — 1X Preplant Treflan @ 1 pint
	1991	Cultivate — 2X	Cultivate — 1X Preplant Treflan @ 1 pint
	1992	Cultivate — 3X	Cultivate — 3X Preplant Treflan @ 1.5 pint

(cont. on p. 30)

(cont. from p. 29)

TABLE 1. Pest management and inputs per acre for alternative systems*

		Organic and low input†	Conventional 2- and 4-Year
INSECTS			
Tomato	1989	Insecticide/acaricide Thiolux @ 5 lb & (**O:** Safer Soap @ 2 gal, **LI:** Thiodan @ 0.33 gal)	Insecticide/acaricide Thiodan @ 0.33 gal & Thiolux @ 5 lb Insecticide Pydrin @ 0.8 pint
	1990	Acaricide Thiolux @ 40 lb Insecticide **LI only:** Pydrin @ 0.08 gal **O only:** Dipel @ 1 lb	Acaricide Thiolux @ 40 lb Insecticide Pydrin @ 0.08 gal
	1991	Acaricide Thiolux @ 10 lb Insecticide Dipel @ 1 lb	Acaricide Thiolux @ 10 lb Insecticide Asana @ 9.6 oz
	1992	—	Insecticide Asana @ 9.6 oz
Corn	1989	—	Acaricide Comite @ 2 pint
	1990	—	Acaricide Comite @ 2.5 pint
DISEASE			
Tomato	1989	**LI only:** Fungicide Dithane @ 3 lb	Fungicide Dithane @ 3 lb & Bayleton @ 0.25 lb

*All inputs are in units of material per acre.
†Inputs are for both systems unless otherwise indicated. **O** = organic and **LI** = low-input
‡Some operations listed as cultivate may be used primarily for reasons other than weed management, but are included here to indicate that they have a control effect on weeds.
§Low-input and organic safflower were replanted to beans.
¶Beans not planted in 1989.

sons when russet mites were first detected. Russet mites are common pests of California processing tomatoes, and over half of all commercial fields in California receive applications annually.

In 1989 two treatments were made to conventional plots to control beet armyworm and tomato fruitworm. In 1990 all processing tomato systems except the organic system received a single treatment for tomato fruitworm control. In 1991 all systems received a single treatment for fruitworm control. No fruitworm control was needed in 1992, probably a result of the earlier harvest date relative to previous years. When treatment for tomato fruitworm was needed, *Bacillus thuringiensis* (Dipel) was used in the organic and occasionally the low-input plots. Fenvalerate (Pydrin) or esfenvalerate (Asana) was used in the conventional plots and occasionally in the low-input plots. In 1989 significantly more ($P < 0.05$) tomato fruitworm damage was found in the organic treatment ($x = 0.94\%$) than in the low-input ($x = 0.51\%$), conventional 2-year ($x = 0.21\%$) or conventional 4-year ($x = 0.28\%$) treatments. No significant differences were observed among the farming systems in other years.

We treated all the plots for potato aphids in 1989; applying insecticidal soap (Safer Soap) to the organic plots and endosulfan (Thiodan) to the other systems. The endosulfan (Thiodan) treatment resulted in significantly lower aphid abundance relative to the soap treatment.

The conventional plots were treated once for stink bugs in 1992. No application was made to either the organic or low-input plots because no organically acceptable pesticides registered for processing tomatoes are known to be effective against stink bugs. Stink bug damage at harvest was much higher in the organic ($x = 10.64\%$) and low-input ($x = 21.43\%$) treatments than in either the conventional 2-year ($x = 6.95\%$) or 4-year ($x = 5.78\%$) treatments. This damage would not have been important if the tomatoes were intended for paste, but would have been a serious problem for whole pack because it causes localized internal tissue to harden and discolor around the area of the bug feeding.

Damage by seedling pests has been very low in all plots, and no treatments have been applied for control. We have noted that seedling damage by cutworms has been somewhat higher in the organic and low-input treatments in which processing tomatoes were preceded by a vetch cover crop.

In the first 2 years of the study (1989 and 1990), we applied the acaricide propargite (Comite) to control spider mites in the conventionally grown corn. Seed corn maggot has been a serious pest in organic and low-

TABLE 2. Pesticide use (lb active ingredient/ac) in each system by crop, 1989 to 1993

Crop	Target pest	Organic	Low Input	Conventional 2-year	Conventional 4-year
Tomatoes	Weeds	0.00	0.00	8.58	8.58
	Insects	9.23	20.03	21.58	21.58
	Disease	2.25	0.00	4.62	4.62
Safflower	Weeds	0.75	0.00	—*	7.41
Corn	Weeds	5.00	0.00	—	13.60
	Insects	0.00	0.00	—	3.65
Winter legume/ wheat	Weeds	0.00	0.00	4.88	4.88
Beans	Weeds	0.00	0.00	—	2.56
Total lb ai/ac	Weeds	5.75	0.00	26.92†	37.03
	Insects	19.23	20.03	43.16†	25.23
	Disease	2.25	0.00	9.24†	4.62
Total		27.23	20.03	79.32	66.88

*— = not applicable. Only tomatoes and wheat were grown in the 2-year rotation.
†Total pesticide use is doubled to represent an area equal to what is used in other systems.

input safflower and corn in the past 2 years. In 1992 maggot damage to safflower stands forced replanting, and about 25% of corn seeds were damaged. Seed corn maggot is known to be most severe in fields that have received applications of manure or contain high amounts of organic matter and in which the soil is sufficiently moist. It is our experience that seed corn maggot should be considered a potential problem whenever a host crop is planted in close rotation with a fall or winter cover crop.

Nematodes. Approximately 30% of the nematodes extracted from soils at the field site over 4 years of the project have been parasites of plants. The most prevalent species were lesion nematodes *(Pratylenchus thornei)*, stunt nematodes *(Tylenchorhynchus/Merlinius)*, pin nematodes *(Paratylenchus* spp.*)* and dagger nematodes *(Xiphinema americanum)*. Of these, the lesion nematode was consistently present following beans and cereals, which are major hosts of this species. It was not detected at levels that would be considered damaging to those crops. *Pratylenchus thornei* is not a parasite of tomato, and its numbers declined during the tomato crop in the rotation sequence. The stunt, pin and dagger nematodes may be parasites of vetch and other leguminous cover crops, but soil temperatures during the fall and winter niche for those crops are probably not conducive to large nematode population increases. Root-knot nematodes *(Meloidogyne* spp.*)* occurred occasionally in the plots, but since the processing tomato varieties grown were root-knot resistant, these nematodes usually occurred in low numbers.

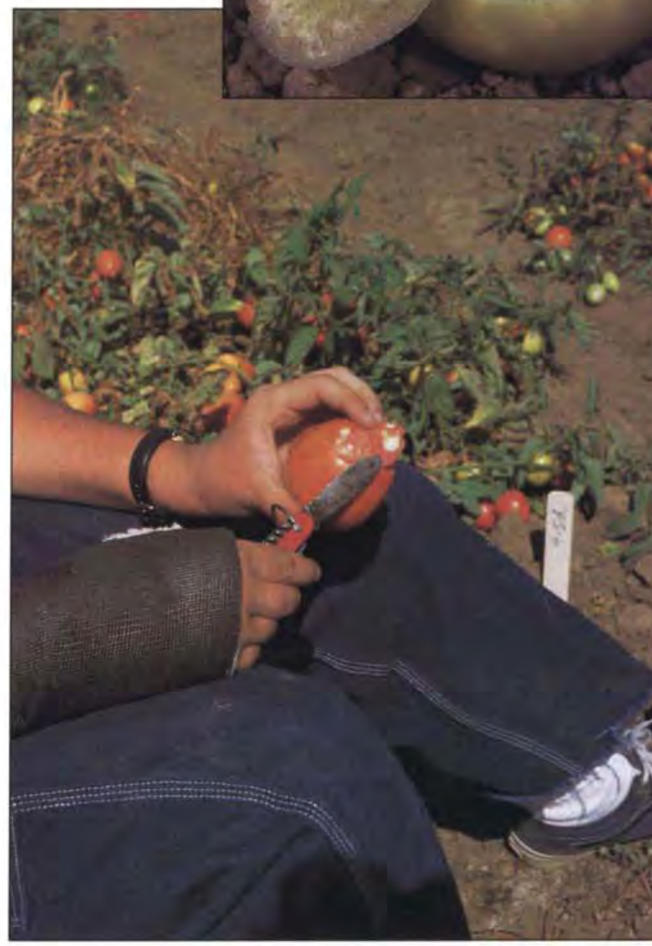
Prior to 1988, the experimental site was a patchwork of smaller research plots for studies on wheat, alfalfa and beans, all managed conventionally. There was considerable variability among nematode species occurring in the plots at the initial 1988 nematode inventory. In the two conventional farming systems, the total numbers of all nematodes in the soil increased between 1988 and 1992, with plant parasitic species representing an increasingly larger proportion of the community. In the low-input and organic systems, the total number of all nematodes, including the plant parasites, decreased in the top 30 centimeters of soil.

There were many factors driving the population dynamics of plant parasitic nematodes under the different farming systems. Interestingly, the diversity of crops in the rotation sequence in all farming systems seemed to be the basis for the stability of population densities of all plant parasitic nematode species. None appeared to be approaching damaging levels at this stage.

Disease. Verticillium appeared to increase in soils on the conventional 2-year rotation plots. The presence of a suitable host, processing tomatoes, more frequently in the rotation was the likely cause of this increase.

Rust occurred every year on all safflower plots. However, it was not observed to cause yield loss, and thus no control treatments were applied. Corn smut was observed in all plots, but the level of its incidence remained below the treatment threshold.

Black mold on processing tomatoes was severe in 1989 as fall rains occurred prior to harvest. We applied mancozeb (Dithane) to conventional plots in an attempt to control black mold, but heavy rainfall made conditions too conducive for disease development, so it provided no noticeable control. Two types of black mold exist, one caused by Stemphyllium, associated with immature sunburned fruit, and the other by *Alternaria*, associated with mature fruit.



Stink bug damage, the white spots on the tomato shown above, at harvest was much higher in the organic and low-input systems than in either of the conventional systems.

Bacterial spot of processing tomato was severe in the spring of 1993, due to the rain and a hailstorm. Although many growers flew on a control treatment of copper hydroxide (Kocide), we did not because aerial applications to small plots were not practical. By the time the fields had dried sufficiently for a ground application, the weather was hot and dry, stopping the epidemic. No pesticide was applied.

Weeds. Percent cover of summer weeds varied by farming system, crop and year (table 4). With the exception of the organic corn plots in 1993, weed cover did not exceed 10%. The cultiva-

Higher populations of pigweed, a preferred host of the armyworm, seemed to aggravate pest problems for the organic tomatoes.

tor setup used varied according to the crop. In processing tomatoes, cultivation was done using a pair of disks, each set within 2 inches of the tomato seedline followed by L-shaped weed knives to clean the sides of the beds. Safflower and beans were cultivated using a rolling cultivator (Lilliston), while corn was cultivated with either a rolling cultivator or an in-row cultivator. Cultivation was not used in wheat or the cover crops. Cultivation generally removed over 90% of the weeds present. In processing tomatoes, hand weeding removed those weeds missed by cultivation. The value of the processing tomatoes justified the added expense of hand weeding (see pp. 34–42), whereas some weeds were tolerated in the other crops. The time required to hand weed plots varied, but on average took 1.5 to 2 times longer on the organic and low-input plots, where herbicides were not used. The shift to tomato transplants for the low-input and organic systems in 1992 and 1993 has not affected the difference in hand weeding time compared to conventional systems.

In the conventional corn plots, we prepared beds in the fall and eliminated emerged weeds by applying herbicide in the winter. A shallow cultivation prior to planting created a dust mulch (approximately 1 inch deep), and we planted corn seed into moisture below the mulch. Very few weeds germinated prior to the first irrigation. The vetch cover crop used on the organic and low-input plots partially depleted the soil moisture in the corn plots. Cover crop incorporation prior to planting caused further drying of the soil. Thus, corn on the low-input or organic plots either was irrigated at planting or required an irrigation much sooner than corn on conventionally treated plots, allowing weeds to germinate and compete with corn soon after planting. Thus, cultivation in the organic or low-input corn plots was only partially effective at uprooting weeds or burying those in the crop row. Large weeds, those almost equal in size to the corn at the time of first cultivation, were difficult to bury without burying the corn and had extensive root systems resistant to removal. In 1993, late spring rains prevented timely cultivation in the low-input and organic plots, resulting in weed cover approaching 40%. An application of 2,4-D (Weedar) controlled most of the escaped weeds in the low-input plots. Either 2,4-D or 2,4-D plus dicamba (Banvel) was used in all years except 1991 to control the broadleaf weeds that emerged in the low-input plots, while weeds persisted on the organic plots.

Weed cover generally varied more by year than by farming system (table 4). The late spring rains in 1993 allowed a greater number of weeds to emerge in most plots. This was particularly evident on organic corn and low-input or organic safflower, where hand weeding and/or herbicides were not used.

The method of weed control used in the farming systems resulted in spe-

TABLE 3. Insect abundance and damage recorded in corn and tomato organic (OR), low input (LI), conventional 4 year (C4) and conventional 2 year (C2) systems in 1989–1992

	1989				1990				1991				1992			
Crop and pest	OR	LI	C4	C2	OR	LI	C4	C2	OR	LI	C4	C2	OR	LI	C4	C2
Corn																
Aphids*	57.8	53.6	59.4	—	5.6	2.3	1.6	—	29.3	39.0	68.7	—	19.0	24.3	30.0	—
Aphid mummies*	43.8	50.8	36.3	—	0.6	0.0	0.0	—	0.0	0.0	0.0	—	0.0	0.0	0.8	—
Mites*	60.9	68.3	31.8	—	41.7	50.0	20.3	—	14.0	26.0	12.0	—	5.0	0.0	0.0	—
Corn earworms†	87.5	81.9	80.0	—	25.6	26.3	18.8	—	98.0	100.0	80.0	—	6.6	7.4	4.0	—
Tomato																
Potato aphids‡	59.4	42.6	20.3	17.8	14.6	15.3	14.4	16.7	15.0	34.2	19.2	55.0	32.0	34.0	10.0	12.0
Aphid mummies‡	8.7	3.9	4.8	3.4	3.3	4.4	1.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fruitworm eggs§	15.0	9.0	12.0	9.0	2.0	5.0	5.0	4.0	6.0	3.0	0.0	1.0	4.0	0.0	2.0	4.0
Parasitized eggs¶	31.8	40.0	36.8	25.0	12.5	0.0	0.0	0.0	45.5	75.0	100.0	80.0	0.0	100.0	0.0	0.0
Armyworm damage#	3.5	0.0	0.0	0.5	4.0	1.5	0.5	1.0	1.0	0.0	3.0	2.0	3.0	3.0	0.0	0.0
Fruitworm damage#	1.5	0.0	0.0	0.5	0.5	1.0	0.5	1.0	1.0	1.0	0.0	1.0	0.0	1.0	2.0	0.0
Scoreable damage**	0.9	0.5	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.4	0.4	0.0
Stink bug damage**	—	—	—	—	—	—	—	—	—	—	—	—	10.6	21.4	6.9	5.8

*Average percent infested lower leaves. Forty leaves per treatment per sampling date.
†Average percent infested ears. Forty ears per treatment replicate per sampling date.
‡Average percent infested leaves. Thirty leaves below highest open flowers per treatment replicate per sampling data.
§Number of viable eggs per 30 leaves below highest open flowers per treatment replicate at peak density.
¶Percent parasitized eggs per 30 leaves below highest open flowers per treatment at peak density.
#Average percent infested fruit at peak observed damage. Fifty fruit per treatment replicate.
**Percent infested fruit at harvest.

cies shifts among the systems. Most notable was the increase in barnyardgrass *(Echinochloa crus-galli)* in the low-input and organic systems. Barnyardgrass populations were extremely low at the beginning of this study due to previous weed control practices on this site. The pre-emergence herbicides napropamide, metolachlor and trifluralin (Devrinol, Dual and Treflan, respectively), used on processing tomatoes, corn and safflower in the conventional systems, were primarily grass herbicides that prevented the buildup of all grasses in these plots. Barnyardgrass can be effectively controlled by cultivation in the seedling stage, but the long seasonal germination period allowed this species to establish after the last cultivations and to set some seed prior to harvest, leading to its increase in the low-input and organic systems.

Purslane *(Portulaca oleracea)* was observed to be more prevalent on the low-input and organic plots in 1991. This succulent weed can remain alive on the soil surface for as long as a week and root again when the field is irrigated. Increasing the waiting period between cultivation and irrigation reduced this weed in the organic and low-input plots during 1992 and 1993.

Several weeds became more prevalent on the conventional plots compared to the low-input or organic plots. Field bindweed *(Convolvulus arvensis)*, a perennial, increased on the conventional 2-year rotation plots. The herbicides used in processing tomatoes were not effective against this species, and the fallow period following wheat allowed further growth. The reduced tillage on these plots relative to the others in this study may also have been a factor in the increase in field bindweed, as observed in numerous midwestern studies when converting to minimum or no tillage. Two other weeds observed to have increased on conventional plots were nightshade *(Solanum* sp.*)* and annual sowthistle *(Sonchus oleraceus)*. Both of these annual weeds also tolerate herbicides used in processing tomatoes and safflower. Nightshade can resemble tomatoes in the seedling stage and is often missed by hand weeding crews. Because herbicides suppress many weed species, those weeds that escape control are able to grow without competition.

TABLE 4. Weed cover in July, 1991 and 1993 relative to farming system and crop

Farming system	1991	Escaped* species	1993	Escaped species
	%		%	
Tomatoes				
Conventional	0.2	Pig	5.5	Pig/night/sow
Short rotation	0.2	Pig	7.5	Pig/night/sow
Low input	0.4	Pig/purs	6.5	Pig/BYG
Organic	0.8	Pig/purs	6.8	Pig/BYG
LSD .05	ns‡	ns		
Corn				
Conventional	0.5	Pig	2.8	Pig/night
Low input	1.8	Pig/purs	1.4	BYG
Organic	3.5	Pig/purs	36.2	Pig/BYG/lamb
LSD .05	2.4		4.9	
Safflower				
Conventional	0.4	Pig	0.2	Lamb/sow
Low input	0.5	Pig/purs	3.8	Lamb
Organic	0.8	Pig/purs	7.2	Lamb
LSD .05	ns	4.2		
Oats/Vetch & Wheat †				
Conventional	0.0		3.0	Vol. wheat
Short rotation	0.0		7.8	Bind
Low input	0.0		4.4	Vol. oat
Organic	0.0		2.9	Vol. oat
LSD .05	ns	ns		

* Bind = field bindweed, BYG = barnyardgrass, Lamb = lambsquarter (*Chenopodium album*), Night = nightshade, Pig = pigweed species (*Amaranthus retroflexus* and *A. blitoides*) , Purs = purslane, Sow = annual sowthistle, Vol. oat = volunteer oat, Vol. wheat = volunteer wheat,

† Field recently disced in preparation for bean planting in 1991. Data source: table 2 Pesticides and application rates (lbs a.i./a) used in each system.

‡ ns indicates no significant difference

Pest conclusions

The shift from conventional to low-input or organic pest control did not result in large increases in relative abundance of most pest species over the period of this study. However, there were some significant short-term problems in individual farming systems. Significantly greater damage occurred to organic and low-input plots by tomato fruitworm in 1989 and stink bugs in 1992, while insecticides prevented damage to conventional plots. Similarly, the cover crop residue appeared to increase damage by seed corn maggot to safflower and corn in two consecutive years.

The major long-term effects were on weeds. The wet spring in 1993 prevented timely cultivation and resulted in increased weed competition where herbicides were not used. The method used to control weeds differed among the systems and resulted in increases in barnyardgrass in low-input and organic systems and field bindweed and nightshade in conventional systems. The shift in weed species resulted in some further shifts in the control strategies, including herbicide changes or increased cultivation frequency, with little or no change in total weed cover.

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