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Integrated Weed Management: Fine Tuning the System

MICHIGAN STATE UNIVERSITY EXTENSION

Integrated Weed Management: Fine Tuning the System

New 12/08

Cover photography: Steve Deming: Grazing goats; Eric Nordell: Onions and cover crop; Erin Taylor: Combining corn, cover crop mix in corn, Danish tines closeup, emerging cotyledon, flamer, jimsonweed seed pods, white campion flower.

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About this guide

"Integrated Weed Management: Fine Tuning the System" is the follow up to "Integrated Weed Management: One Year's Seeding…" (E-2931) which was released in February 2005. Feedback from an extensive survey of "One Year's Seeding…" was positive, however it was determined that there were many questions remaining regarding weed management in sustainable farming systems. "Fine Tuning the System" was written to further address specific areas of interest in weed management.

Similar to "One Year's Seeding…" this guide does not provide detailed management plans. Each chapter looks at how different cultural and management practices affect weeds. Our goal was to go one step beyond compiling written information from researchers and extension personnel to also include input from experienced growers as much as possible. Chapter 1 presents several diverse crop rotations from growers around the North Central region along with the benefits and issues seen by the grower. Chapters 2, 3, 4 and 5 each feature a grower with extensive experience in the chapter's subject. And finally, ten grower-designed on-farm trials testing IWM practices are outlined in Chapter 7. These on-farm trials were funded by the same grant that supported the publication of "One Year's Seeding…"

Erin Taylor

Chapter 1

Diverse Crop Rotations

Authors: Erin Taylor and Karen Renner

Crop rotations are a key component of all farming systems. Crop rotations are designed to manage nutrients and pests, control soil erosion, and increase soil organic matter and soil quality (Figures 1-3).

Complex crop rotations can improve weed management. Changes in planting dates and other cultural practices throughout the crop rotation stop weed species from establishing in unchanging niches. Many experiments provide evidence that a rotation of two or more crops can reduce weed populations compared with continuous production of one crop. Liebman and Dyck (1993) reviewed 27 comparisons of rotational vs. monoculture crop production. Weed densities were lower in crops following a rotation compared with crops following a monoculture in 21 cases, similar in five cases, and higher in one case. There are fewer differences in weed populations in a monoculture of corn compared with a corn-soybean rotations because these crops are managed similarly in terms of planting time, weed control timing, and harvest time. (Kegode et al. 1999).

Figure 1. Alfalfa. Erin Taylor

Figure 2. Oats. Erin Taylor

Complex crop rotations can improve weed management.

Figure 3. Corn. Erin Taylor

Crop rotations that are complex and include cover crops:

- **Decrease pest pressure from insects, weeds and diseases**
- **Enhance biological activity in the root zone**
- **Increase soil organic matter and improve soil quality**

Adapted from NewFarm
http://www.newfarm.org/features/1002/crop_rotations/index.shtml

"That forage crop is the key to your rotation for weed control in my book." –Gary Reding


Figure 4. Giant foxtail in soybean. Erin Taylor


Figure 5. Pigweed in soybean. Erin Taylor

Adding a perennial forage crop or a pasture crop in a rotation reduces weed populations. The annual broadleaf weed seed-bank declined when fields were in perennial crops but increased when planted to annual crops during conversion to organic farming in Norway (Sjursen, 2001).

The effectiveness of a crop rotation in reducing weed populations depends on the specific crop that initiated the rotation. Starting a rotation with a grass hay crop increased grass weed populations in corn and soybeans (Figure 4), while starting with corn and soybean in the first two years of a six year rotation increased pigweed and other broadleaf weeds in farm fields (Figure 5) (Teasdale et al. 2004).

Longer rotations of crops with diverse life-cycles and physical characteristics can reduce weed seed bank populations and the abundance of important annual broadleaf weeds in organic production systems (Teasdale et al. 2004).

Weed control and crop yield were better in organic corn and soybean when they were part of a 4-year corn, soybean, oat, alfalfa rotation than a 2-year corn, soybean rotation. (Porter et al. 2003)

The USDA-ARS did a 10-year study in Maryland comparing five cropping systems—two conventional and three organic systems. In the organic systems, a rotation that included corn, soybean, wheat and orchardgrass hay resulted in an average corn grain yield that was 30% greater than a simple corn–soybean rotation and 10% greater than a corn–soybean–wheat rotation. Weed competition decreased and nitrogen availability increased in corn as the rotation length and complexity increased. Interestingly, soybean and wheat yields in the organic systems were not affected by the length or complexity of the crop rotation (Figure 6) (Cavigelli et al. 2008).


Figure 6. Soybeans growing next to corn in the Cavigelli et al. conventional versus organic rotation study. Michel Cavigelli

Crop rotation examples

There are two very good references that include examples of crop rotations. One reference is the Organic Field Crop Handbook from the Canadian Organic Growers (www.cog.ca). This publication gives several examples of crop rotations in Chapter 20 and provides details about the rotation. Another excellent reference on crop rotations is from the NorthEast Organic Network (NEON) (www.neon.cornell.edu/croprotation). Their web site includes a crop rotation manual and planning worksheets. In another link at this web site (www.neon.cornell.edu/croprotation/DACUMcroprotation.pdf) (Mohler and Johnson 2008), there is a published guide where 12 experienced organic vegetable farmers discuss crop rotation. This expert farmer group developed a series of rotation charts detailing the actions and decisions related to rotations on each of their farms which are located from southern Maryland to northern Maine and range from 3 to 200 acres. These farmers tended to rotate crop family (e.g. grains, legumes, root crops, etc.) as much as specific crops, and responded to field situations season by season.

Strategies for optimizing rotation effects on weed suppression:

- **Alternate early and late season vegetables/crops**
- **Use weed suppressive cover crops**
- **Use 'cleaning crops' (e.g. potatoes) where weeds can be easily managed before crops in which it is difficult to control weeds (e.g. carrots)**

Characteristics of weeds most likely to be reduced under diverse rotations:

- **Short persistence in soils (e.g. galinsoga); long lived weed seeds can come back even with long rotation**
- **Short dispersal distance of seeds or other propagules**
- **Specialists (i.e. weeds that do well in specific crops rather than many different crops)**

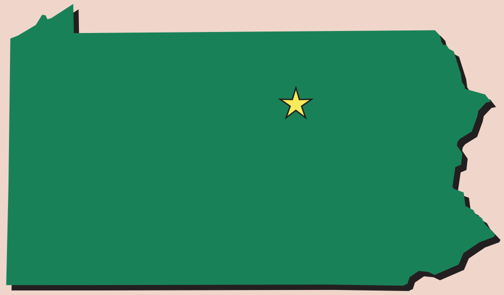
These expert organic growers rotate cash crops, cover crops, the application of mulches and composts, and tillage practices. In many situations, revenue was a more influential driver of the vegetable crop rotation than biology. Decisions are made by each grower's personal guidelines, farm goals and limits.

In the following pages, farmers in Michigan and surrounding states have outlined examples of a four to nine year rotations in one of their farm fields. They have included tillage practices, cover crops and nutrient management to provide the reader insight into why these rotations work on their farms. It is important to recognize that a crop rotation that works on one farm or in one field, might not work in another. These rotations serve as a guideline for other farmers interested in changing or developing a more complex crop rotation.

Weed problems can increase in corn if the previous crop was wheat underseeded with red clover and the red clover did not establish well (Singer et al. 2000).

The effectiveness of a crop rotation in reducing weed populations depends on the specific crop that initiated the rotation.

Beech Grove Farm (Trout Run, PA)



Anne and Eric Nordell

Organic since 1983, certified as of 1987.

Acreage: 60 Pasture

7 Vegetable-fallow rotation

<1 Hoophouse production

Livestock: Work horses, laying hens, pigs

Soil type(s): Silt loam

Typical monthly precipitation (inches):											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3	3	3	3	4	4	4	3	4	3	4	3

Rotation details

Year 1: Over time summer weed problems have been eliminated at the Beech Grove Farm using a summer fallow, so the fallow period has now been switched to the spring to target winter/spring weeds in the seed bank. After the fallow period sorghum-sudangrass is planted with clover. The cover crops are mown when the grass reaches 3 to 4 feet tall (leaving 6 to 8 inches of stubble), totaling about 3 mowings during the season. The mowing encourages deeper rooting of the grass and above ground growth of both clover and grass. This summer cover crop seeding prevents the establishment of fall/winter weeds (e.g. chickweed) and blown in spring weeds (e.g. dandelion).

Year 2: Compost (7 to 8 yards per acre) is applied to the clover in early spring. In mid-May the clover is shallowly incorporated to 2 to 3 inches using sweeps. This shallow tillage preserves the soil tilth and moisture, reduces erosion, and limits the number of new weed seeds brought to the surface. Once the late season vegetables are planted, straw mulch is laid between the rows to hold moisture and protect the soil over the winter.

Year 3: Again the field is left fallow in the spring and a stale seedbed approach is used to flush out weeds. In the early summer a cover crop of field peas is planted. This cover crop is shallowly incorporated in the summer. Compost (7 to 8 yards per acre) is then spread, oat seed is broadcast, and ridges are formed using disc hillers. This method creates ideal conditions for sheet composting. The oats winter kill when the ground freezes.

Year 4: In the spring the winter-killed oats are chopped and the ridge tops are lightly tilled using a rotary hoe to preserve soil tilth, moisture, aeration, and drainage. Early season vegetables are then planted on the ridges and the valleys are cultivated as necessary. After the residue in the valleys breaks down hairy vetch is seeded in a single row in the center (i.e. between vegetable rows). This provides nitrogen for the subsequent cash and cover crops.

Benefits of this rotation

- Cool season weeds, which can be problematic in the early spring or late fall vegetables, are showing a big decline; no handweeding!
- Fallow periods, cover crops, and reduced tillage allows nitrogen, organic matter, and soil tilth to be maintained with only the addition of the compost generated from four work horses and two pigs (rock minerals and straw are also added to the compost).
- Consistent yields have been achieved without irrigation.

Figure 7. Alternating rows of summer squash, lettuce, spinach and peas growing in late June.

Issues in this rotation

- This rotation assumes summer weeds are no longer a problem.
- It may be necessary to trim back the interseeded hairy vetch vines.
- In a very wet summer, spring/fall weeds may establish in summer planted peas or sorghum-sudangrass/clover mix.
- Cultivation equipment must be able to handle residue.
- Flea beetle pressure in the Brassica crops seems higher following clover compared to a rye/vetch mix.

Year	Season	Crop/Cover crop	
Y1	Winter	Rye	
	Spring		
	Summer	Sorghum-sudangrass	Clover (medium red)
	Fall	3x	
Y2	Winter		
	Spring		
	Summer	Late season vegetables (Alt. rows of Brassicas, salad mix, lettuce and spinach)	Wheat mulch pathways
	Fall		
Y3	Winter		
	Spring		
	Summer	Field peas	
	Fall	Oats (on ridges)	
Y4	Winter		
	Spring	Early season vegetables spinach, peas, potatoes, onions strawberries)	Hairy vetch
	Summer		
	Fall	Rye	

= harvest = winter kill = incorporated = mowed

Figure 8. Deep plowing mowed rye and perennial weeds to begin the summer fallow period. Anne Nordell

Kellogg Farms (Carson City, MI)

Dennis Kellogg

Organic since 1996, certified as of 2001.

Acreage‡: 161 Field crops

47 Forages

‡Changes year to year.

Livestock: Beef cattle

Soil type(s): Mostly sandy clay loam, some sandy loam

Typical monthly precipitation (inches):											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2-4	2-3	3-4	4	3-4	2-3	1-2	1-2	2-3	1-2	2-3	2-4

Rotation details

Year 1: Clover is frost seeded into the wheat in the early spring. The wheat provides a crop to sell, while the wheat straw and clover provide cattle feed. Chopping the weeds with the wheat and clover and feeding them to the cattle reduce future weed problems.

Year 2 and 3: The clover helps build the soil and self seeds for future years (hard seeds germinate later). During these two years the clover (and any weeds) is periodically harvested for cattle feed.

Year 4: The clover is tilled in the spring using either a moldboard plow or a field cultivator, then, depending on market conditions either corn or soybeans are planted for the cash crop. Here we show corn (there is also the possibility of leaving some clover for seed harvest). The corn is rotary hoed and cultivated at least two times for weed control. In the fall after harvest the corn stalks are windrowed and chopped (this helps speed up the decomposition of the corn and weed plant material). Cattle manure is applied and worked in using either a disk of a field cultivator. Rye is then planted for the winter cover crop.

Year 5: The rye is incorporated in the spring. Soybeans are planted and weeds are controlled using a rotary hoe and cultivator. After harvest the field is disked and planted to wheat.

Benefits of this rotation

- There is always a winter cover crop (wheat, rye, or clover) to protect the fields.
- During the row crop phase of this rotation there is a place to utilize the manure produced from the cattle on the farm.
- Having cattle on the farm is important to the overall nutrition and weed management of this rotation.

Issues in this rotation

- As always the weather can cause problems with cultivating and yields are impacted due to poor weed control.

Figure 9. Clover.

Year	Season	Crop/Cover crop
Y1	Winter	Wheat
	Spring	Clover (Medium red or mammoth)
	Summer	
	Fall	
Y2	Winter	
	Spring	
	Summer	
	Fall	
Y3	Winter	
	Spring	
	Summer	
	Fall	
Y4	Winter	
	Spring	Corn (or soybeans)
	Summer	
	Fall	Rye
Y5	Winter	
	Spring	Soybeans
	Summer	
	Fall	Wheat (Soft red winter)

= harvest = winter kill = incorporated = mowed

Figure 10. Corn.

Ivan Morley Farms (Standish, MI)

Ivan Morley

Organic since 1999, certified as of 2001.

Acreage‡: 441 Field crops
64 Forages
156 Fallow

‡Changes year to year.

Livestock: None

Soil type(s): Varies from sandy to loam, some heavy clay

Typical yearly precipitation: 30 inches

Rotation details

Year 1: Poultry manure was applied the previous fall at 2 to 3 tons per acre. Medium red clover is frost seeded into the wheat in the early spring. After wheat harvest the clover is allowed to grow and then chisel plowed late in the fall to add as much nitrogen as possible.

Year 2: Corn is planted in year 2. After corn harvest the stubble is chisel plowed. In the future it may be moldboard plowed as this seems to result in cleaner fields the following year.

Year 3: Soybean is planted in year 3. After soybean harvest in the fall the ground is worked and spelt is planted.

Year 4: Same as year 1.

Year 5: Same as year 2.

Year 6: Same as year 3 with dry edible beans instead of soybean.

Issues in this rotation

- Thistles and nutsedges have started to become a real problem in this rotation, so Mr. Morley is starting to summer-fallow some land every year.
- The poultry manure not only helps the crop, but it also encourages weed growth.

Figure 11. Soybeans.

Figure 12. Dry beans.

Figure 13. Clover interseeded into wheat.

Year	Season	Crop/Cover crop
Y1	Winter	Wheat
	Spring	Clover (Medium red)
	Summer	
	Fall	
Y2	Winter	
	Spring	Corn
	Summer	
	Fall	
Y3	Winter	
	Spring	Soybeans
	Summer	
	Fall	Spelt
Y4	Winter	
	Spring	Clover (Medium red)
	Summer	
	Fall	
Y5	Winter	
	Spring	Corn
	Summer	
	Fall	
Y5	Winter	
	Spring	Dry edible beans
	Summer	
	Fall	Wheat

= harvest = winter kill = incorporated = mowed

Wiley Grass Farm (Schoolcraft, MI)

Matt Wiley

Certified organic since 1999.

Acreage: 240 Field crops

Livestock: None

Soil type(s): Kalamazoo loam

Typical yearly precipitation: 32 inches

Rotation details

Year 1: Medium red clover is incorporated around April 25th about 2 ½ inches deep using a rotovator. In early May the field is then worked again with the rotovator and then harrowed just before planting. Fish emulsion is applied at corn planting and then side-dressed once. In the fall after harvest, lime and chicken manure are applied and rye is planted for the overwinter cover crop.

Year 2: The rye is tilled in late April to about 2 ½ inches and again in early May. It is then harrowed just before planting snap beans. Four days after planting, the beans are weeded using a tined weeder. The rotary hoe follows three times at a four day interval. The crop is then cultivated two times. Spelt is planted after harvest.

Year 3: Clover is frost seeded into the spelt in March. After spelt harvest in late July the stubble is mown to reduce annual weeds and to allow for even growth of the clover. In the fall chicken manure (2 tons per acre) and lime (500 lbs. per acre) are applied over the clover.

Year 4: Same as Year 1.

Year 5: Same as Year 2, only with soybeans instead of snap beans.

Year 6: Same as Year 3.

Figure 14. Spelt underseeded with clover.

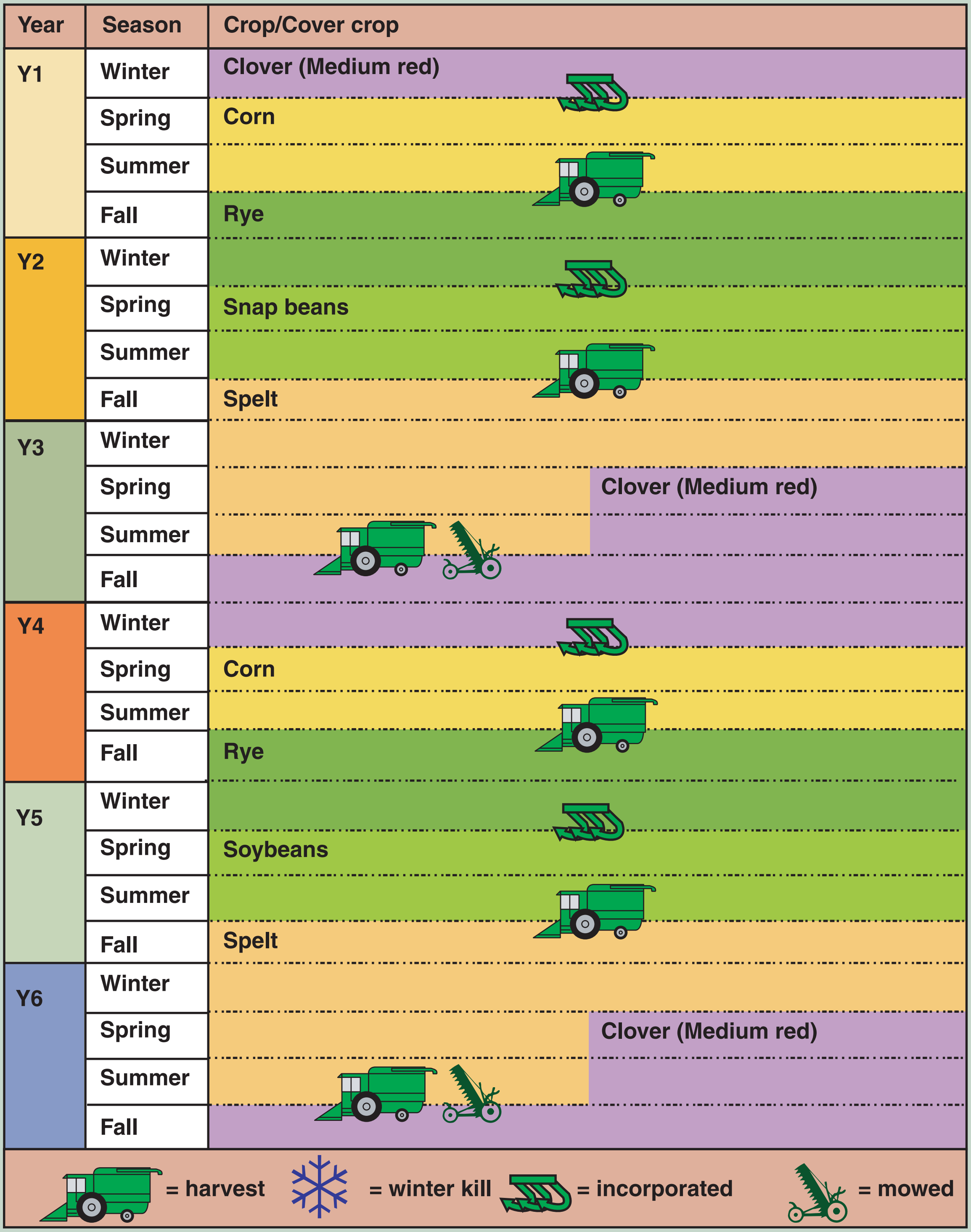
Benefits of this rotation

- Weed pressure has decreased and yields have increased.
- The soil is less compacted with the shallow tillage and it holds moisture better.

Issues in this rotation

- Snap beans and soybeans need to be harvested by early- to mid-September so that spelt can be planted on time.

Figure 15. Matt Wiley inspecting his soybean crop.


Year
Season
Crop/Cover crop
Y1
Winter
Spring
Summer
Fall
Clover (Medium red)
Corn
Rye
Y2
Winter
Spring
Summer
Fall
Snap beans
Spelt
Y3
Winter
Spring
Summer
Fall
Clover (Medium red)
Y4
Winter
Spring
Summer
Fall
Corn
Rye
Y5
Winter
Spring
Summer
Fall
Soybeans
Spelt
Y6
Winter
Spring
Summer
Fall
Clover (Medium red)
= harvest
= winter kill
= incorporated
= mowed

Standard Process, Inc. (Palmyra, WI)

Christine Mason- Farm Manager

Organic since 1990.

Acreage:	168 Field crops
	151 Vegetables
	102 Forages
Livestock:	None
Soil type(s):	Silt loam, clay loam, sandy clay loam, Martinton, etc.

Typical yearly precipitation: 36 inches

Rotation details

Year 1: A mix of field peas, oats (50 lbs. per acre), and clover (10 to 20 lbs. per acre) are planted early in the spring. Two to three weeks before planting red beets, the cover crop is rotovated, left to sit for one week, cultivated with a soil finisher, left another week, cultivated again with the soil finisher, and then planted to the beets.

Year 2: Crimson clover is seeded early in the spring (25 lbs. per acre). A few weeks before planting the cash crop the cover is rotovated, left for a week, and then the soil finisher is used. There is not as much biomass with crimson clover as with the mix from year 1, so it does not require repeated tillage events. Following incorporation, the field is rotovated, gypsum is applied (200 lbs. per acre), and the field is cultivated using a soil finisher. Then, in late June, kidney beans are planted.

Figure 16. Field of peas in bloom.

Year 3: Buckwheat is grown twice sequentially as a cash crop.

Year 4: Sweet peas are drilled in early April. Following pea harvest, a crimson clover cover crop is planted (25 lbs. per acre) and left over winter.

Year 5: The clover is incorporated early in the spring and then chickling vetch is planted as a seed crop. Radish (for market) is planted in the fall following chickling vetch seed harvest.

Year 6: Barley is drilled in early April. After barley harvest, berseem clover is planted. The clover is incorporated in the fall.

Benefits of this rotation

- A large crop diversity (i.e. 21) is a huge asset for rotations on this farm.
- Extremely productive yields.
- No disease pressure.
- Minimal insect pressure (only requiring management in the Brassica crops and pumpkins).
- Rely extensively on green manures, using composted chicken manure only before small grains.
- Oats (and barley) are very beneficial cover crops because they winter kill (requiring no management) and create a nice mat for spring weed control.

Figure 17. Radish field.

Issues in this rotation

- Ms. Mason now prefers chickling vetch to crimson clover for early spring plantings because it germinates better in cold weather. Additionally, crimson clover as an over-winter cover only survives ½ the time.
- Chickling vetch alone will not provide adequate weed suppression; it needs to be planted with oats or barley.

- Berseem clover grows faster than crimson clover, however it dies at 31° F.

Other notes

- Rye and wheat do not work as cover crops on this low lying flat farm because the soil does not dry out, resulting in delayed planting.

Year	Season	Crop/Cover crop
Y1	Winter	
	Spring	Field peas, oats, clover (Crimson)
	Summer	Red beets
	Fall	
Y2	Winter	
	Spring	Clover (Crimson)
	Summer	Barley
	Fall	
Y3	Winter	
	Spring	
	Summer	Buckwheat (cash crop)
	Fall	Buckwheat (cash crop)
Y4	Winter	
	Spring	Peas (Sweet)
	Summer	Clover (Crimson)
	Fall	
Y5	Winter	
	Spring	Chickling vetch
	Summer	
	Fall	Radish
Y6	Winter	
	Spring	Barley
	Summer	Clover (Berseem)
	Fall	

= harvest = winter kill = incorporated = mowed

Simmons Family Farms (North Branch, MI)

John Simmons

Organic since 1996.

Acreage: 400 Field crops
100 Forages

Livestock: None

Soil Type(s): Capac, Brookstone, Locke and Linwood

Typical annual precipitation: 26 inches

Rotation details:

Year 1: Corn is planted on clover plow down from prior year's seed harvest. Nitrogen needs are adequately met. Compost is sometimes applied to meet organic matter, microbial, and other nutrient needs. After corn harvest, if conditions permit, rye is planted.

Year 2: After rye is incorporated, soybeans are planted. They respond well to the low nitrogen environment created by the decomposing rye and corn stalks. No fall cover crop is planted to avoid issues with the following oat crop.

Year 3: Oats and clover are interplanted in the early spring. After oat harvest the clover is plowed down to prepare the ground for spelt. The clover provides adequate nitrogen for the spelt. Spelt is planted in the fall.

Year 4: The spelt is interseeded with clover in the early spring. After spelt harvest, the straw is harvested and "loaned" to a neighboring farm for bedding material. The straw and manure are then returned to the Simmons' farm. If the environmental conditions are appropriate for the clover to set seed it is harvested in the fall. If needed, manure and compost are applied and incorporated.

Figure 18. Sunflower field.

Year 5: Sunflowers are planted in the spring and harvested in late summer. After sunflower harvest, if conditions permit, rye is planted as the overwinter cover.

Year 6: The rye is allowed to grow throughout the spring before it is incorporated. In mid-July buckwheat and clover are interplanted. This late timing allows for any volunteer sunflowers to be plowed down. The buckwheat is harvested in the fall and the clover is allowed to remain.

Year 7: The clover is allowed to grow undisturbed all year until it is harvested for seed in the fall. Any volunteer buckwheat plants are choked out by the dense clover.

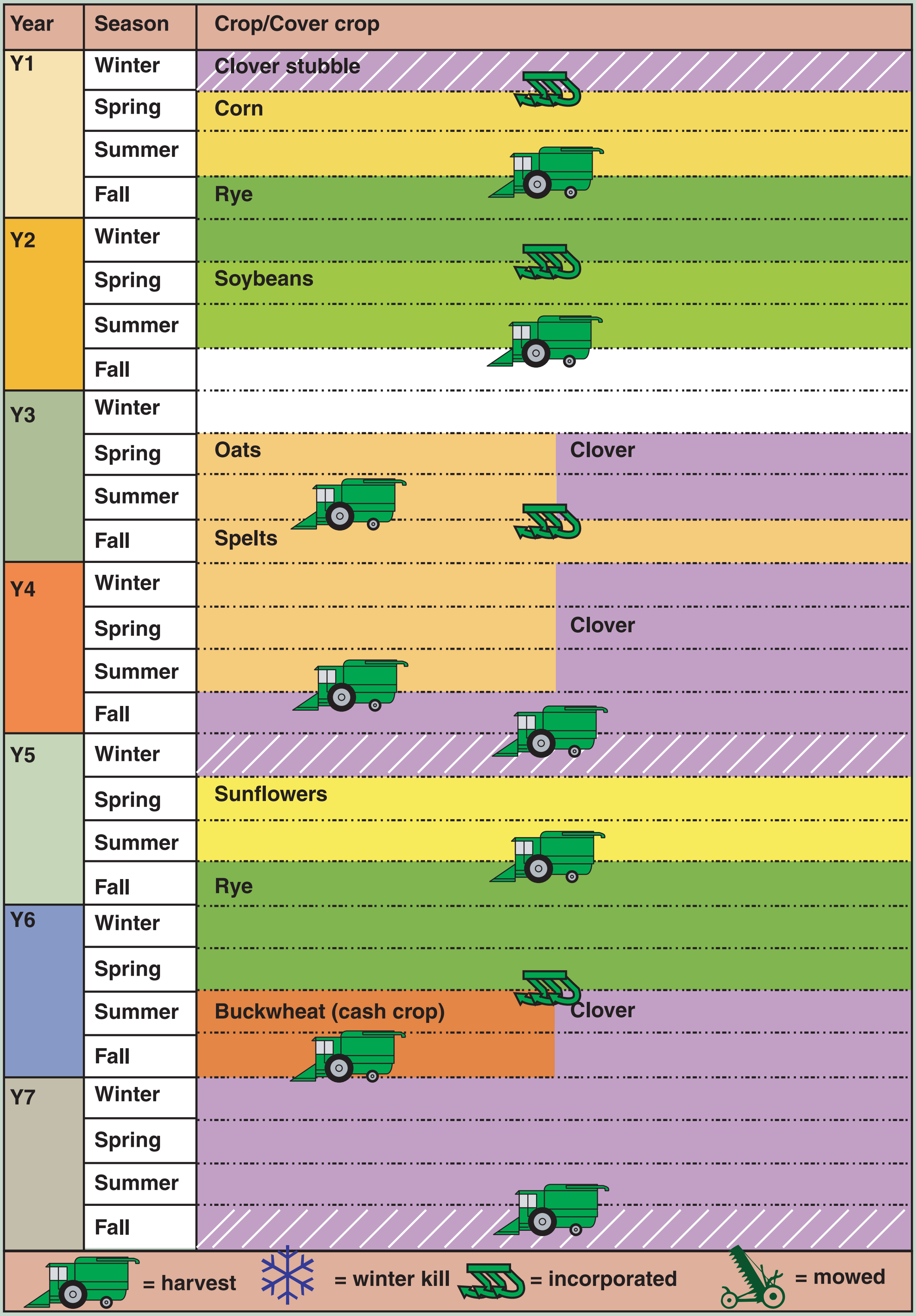
Figure 19. Buckwheat.

Benefits of this rotation

- The soil conditions and percent organic matter improve with long-term clover use.
- The wide range of crop species and varying nutrient demands allow for efficient "pulsing". Also, the varied planting and harvest dates spread out field work.
- Windows are available for summer fallow weed control.

Issues in this rotation

- Occasional volunteers from seed crops.


Year
Season
Crop/Cover crop
Y1
Winter
Spring
Summer
Fall
Clover stubble
Corn
Rye
Y2
Winter
Spring
Summer
Fall
Soybeans
Y3
Winter
Spring
Summer
Fall
Oats
Clover
Spelts
Y4
Winter
Spring
Summer
Fall
Clover
Y5
Winter
Spring
Summer
Fall
Sunflowers
Rye
Y6
Winter
Spring
Summer
Fall
Buckwheat (cash crop)
Clover
Y7
Winter
Spring
Summer
Fall
= harvest
= winter kill
= incorporated
= mowed

Blue Moon Farm (Urbana, IL)

Jon Cherniss

Organic since 1988.

Acreage: 20 Vegetable

$^1/_4$ Hoophouse

Livestock: None

Soil types: Mostly catlin and some flannagan

Typical annual precipitation: 42 inches

Rotation details:

Year 1: Oats are planted in the spring and Austrian winter peas are planted in the fall to provide a nitrogen source for the following year. The Austrian winter peas are killed by frost in the fall.

Year 2: Tomatoes and peppers are transplanted in alternating rows between early April and early May.

Year 3: Field peas are planted in the early spring to provide nitrogen. They are plowed down by the beginning of July in preparation for planting fall vegetables, such as broccoli.

Year 4: The field is allowed to rest with three sequential cover crops for year 6; oats in the spring, followed by sudangrass in the summer, and finally Austrian winter pea in the fall. The sudangrass is mowed once or twice during the summer to encourage above- and belowground growth and to prevent seed production. It is then flail mowed prior to incorporation.

Year 5: Salad greens are planted in the spring and again in the fall.

Year 6: Again, the field is allowed to rest with spring oats, followed by sudangrass, followed by a mix of hairy vetch and rye in the fall. Again, the sudangrass is mowed as in year 6.

Year 7: The hairy vetch and rye are plowed in the spring and tomatoes are transplanted by the beginning of June.

Figure 20. Green pepper.

Figure 21. Broccoli.

Benefits of this rotation

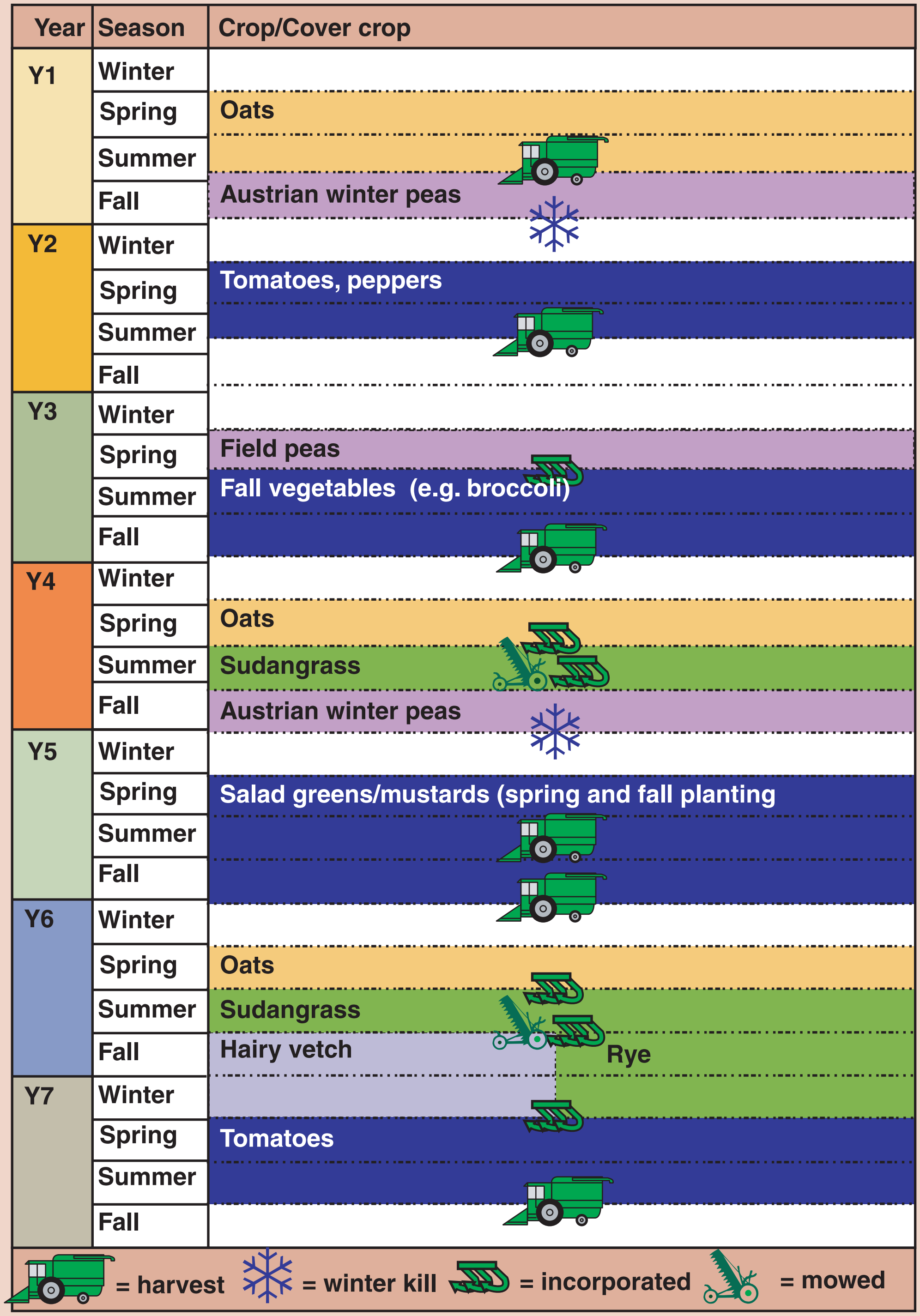
- This rotation, along with our other rotation schemes, has increased organic matter.
- The soils on this farm have withstood periods of intense precipitation better than neighboring farms.
- This program relies almost exclusively on green manures for fertility.

Issues

- Only 50% of the acrage at the Blue Moon Farm is available for cash crops every year.
- The annual cover crops take a lot of time to manage and require a lot of tillage.

Other notes

- Prior to this rotation we rotated 3 years of sod followed by 3 years of vegetables. Canada thistle became a real problem durng the vegetable years, so now we are alternating vegetables and covef crops every other year.


Year
Season
Crop/Cover crop
Y1
Winter
Spring
Summer
Fall
Oats
Austrian winter peas
Y2
Winter
Spring
Summer
Fall
Tomatoes, peppers
Y3
Winter
Spring
Summer
Fall
Field peas
Fall vegetables (e.g. broccoli)
Y4
Winter
Spring
Summer
Fall
Oats
Sudangrass
Austrian winter peas
Y5
Winter
Spring
Summer
Fall
Salad greens/mustards (spring and fall planting
Y6
Winter
Spring
Summer
Fall
Oats
Sudangrass
Hairy vetch
Rye
Y7
Winter
Spring
Summer
Fall
Tomatoes
= harvest
= winter kill
= incorporated
= mowed

Rider Landing (Deshler, OH)

Ken and Nan Rider

Organic since 1996.

Acreage:	525 Field crops
	175 Forages
Livestock:	None
Soil type(s):	Hoytville clay

Typical monthly precipitation (inches):											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1-2	1-2	2-3	3	3-4	3-4	3-4	3-4	2-3	2-3	2-3	2-3

Rotation details

Year 1-3: Alfalfa is grown and cut as needed. The period in which alfalfa is grown ranges from 3 to 5 years.

Year 4: Coming out of 3 to 5 years of alfalfa greatly helps in reducing weed pressure, especially Canada thistle. Compost is applied over the alfalfa and it is moldboard plowed in the spring (or late fall in the previous year). After plowing, corn is planted.

Year 5: After corn harvest in year 4 the field is plowed either in the fall, or if there is thistle pressure, it is plowed in the late spring. No compost is applied at this time. Soybeans are planted. Immediately after harvest the bean stubble is disked and spelt is planted. Another option would be to no-till drill the spelt seed into the bean stubble (spelt would need to be dehulled). This would reduce surface disturbance and allow for more predation of weed seeds by insects, mice and birds.

Year 6: The spelt is underseeded with medium red (or mammoth red clover if the spelt has long straw) in the early spring. The clover remains after spelt harvest and may be plowed in the fall to remove spring work load and weather risk or plowed next spring. If the soil is heavy, it is better to plow the clover in the fall.

Year 7: Compost is applied over the clover and then plowed. Corn is planted. After harvest the corn stubble is either left alone, moldboard plowed, or chisel plowed, again depending on weed pressure and workload.

Year 8: Soybeans are planted. After harvest the soybean stubble is disked and soft red winter wheat is planted.

Year 9: After harvesting the wheat the straw is incorporated and a fine seedbed is prepared for the alfalfa planting in late summer (usually August).

Benefits of this rotation

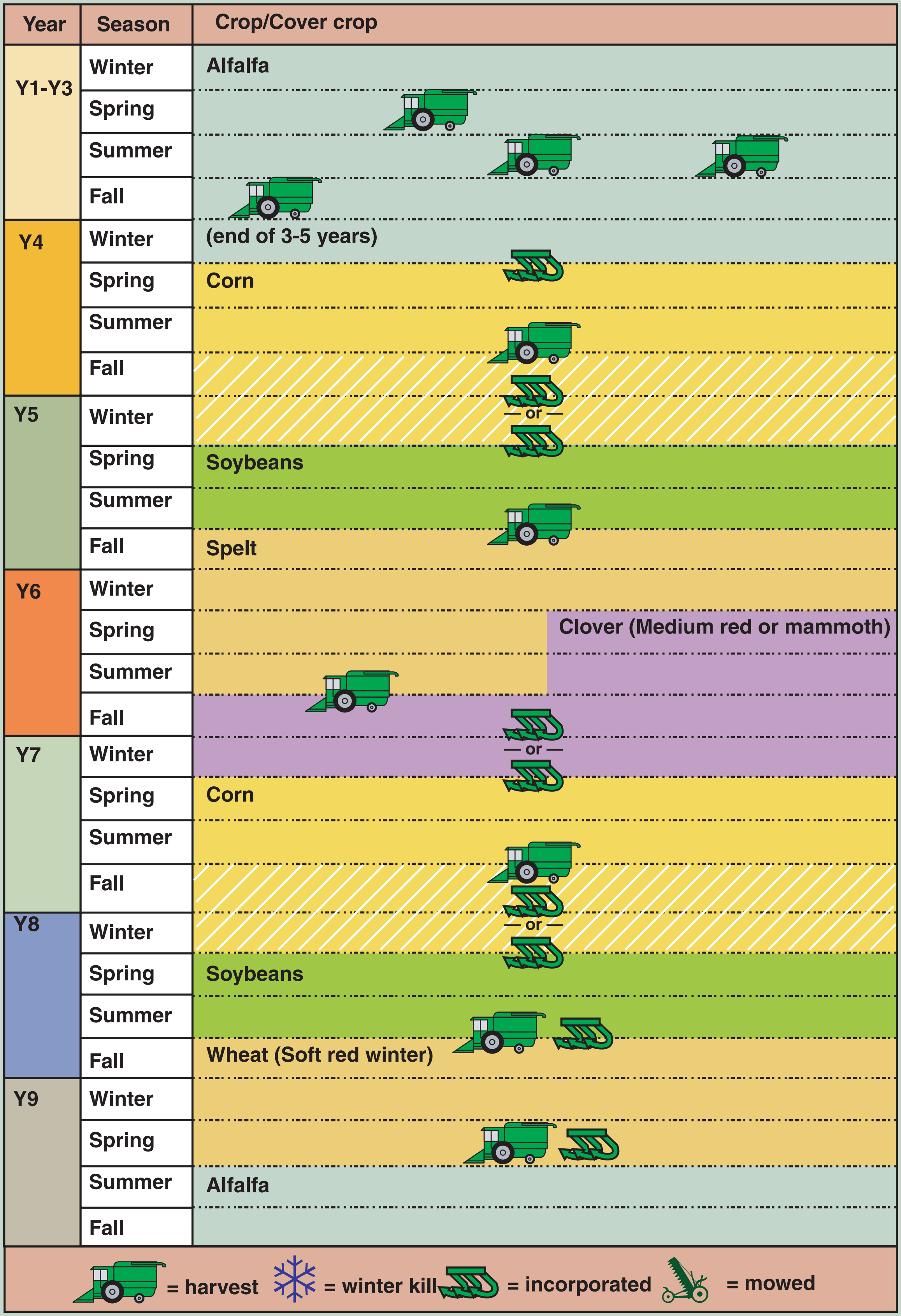
- This rotation allows for flexibility with the weather conditions, weed pressure and soil type.
- Rye, oats and oilseed radish can easily be worked into this rotation.

Issues in this rotation

- Over working the Hoytville clay can result in tight soil that is impervious to water.

Other notes

- Shallow plowing works best on corn stalks.
- Do not plant mammoth red clover in soft red winter wheat; it may be too tall at wheat harvest.
- Beware of using hairy vetch in the rotation if selling spelt for food grade flour. It leaves foreign material in the final product and though it is not harmful, it will be rejected by the processor.


Year
Season
Crop/Cover crop
Y1-Y3
Winter
Spring
Summer
Fall
Alfalfa
Y4
Winter
Spring
Summer
Fall
(end of 3-5 years)
Corn
or
Y5
Winter
Spring
Summer
Fall
Soybeans
Spelt
Y6
Winter
Spring
Summer
Fall
Clover (Medium red or mammoth)
or
Y7
Winter
Spring
Summer
Fall
Corn
or
Y8
Winter
Spring
Summer
Fall
Soybeans
Wheat (Soft red winter)
Y9
Winter
Spring
Summer
Fall
Alfalfa
= harvest
= winter kill
= incorporated
= mowed

Richard Stuckey Farm (Alma, MI)

Richard Stuckey

Organic since 2000.

Acreage: 119 Field crops

9 Vegetables

Livestock: None

Soil Type(s): Nester loam (58%), Kawkawlin loam (40%) and Menominee loamy sand (2%)

Typical monthly precipitation (inches):											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
<1	1	3	4	4	2	3	4	1	3	1	3

Rotation details

Year 1: After harvesting a short season vegetable (e.g. snap beans) manure, compost, and/or mineral supplements can be applied and incorporated. Also, if time permits, summer fallowing can be employed to control Canada thistle, common milkweed, and common dock. Wheat is then planted.

Year 2: Clover is frost seeded into the wheat (at least 16 lbs. per acre) using a broadcast seeder. After wheat harvest the straw is flail chopped to open the canopy for the clover. The clover may be flailed/mowed one or more times to prevent seed set and encourage clover root growth.

Year 3: The clover is flail chopped in the spring to control weeds. This practice sets the seed harvest date back a week or two. At harvest the clover is mown with a swath mower and allowed to dry in the field before thrashing.

Year 4: Soybeans are planted in 30-inch rows in the spring. Following harvest, rye is planted (1.5-2.5 bu. per acre). Rye helps to uptake nutrients, especially nitrogen, remaining from the soybean crop and stores it for the next year's corn.

Year 5: The rye is incorporated in the spring. A 90-95 day corn is planted in 30-inch rows. When the corn is around knee high a four-way cover crop mix is broadcast over the field (i.e. mammoth red clover + ryegrass + oilseed radish + hairy vetch). If the mix is unavailable, mammoth red or medium red clover is used alone. After corn harvest, the stubble is flail chopped to control weeds and open the canopy to maximize cover crop growth. Some years may require the fall cover crop to be flailed to prevent cover crop seed set.

Figure 22. Clover in wheat stubble.

Year 6: Before moldboard plowing, the cover crop mix may need flailing in the early spring to control/prevent cover crop seed set. Planting navy beans two weeks after moldboard plowing allows time for the cover crop biomasses to decompose. After navy bean harvest the soil is prepared and a cover crop mixture of cereal rye and perennial ryegrass is planted for a seventh year fallow.

Benefits of this rotation

- Usually there is a cover crop present over the winter to protect the soil and feed soil life forms.
- In longer rotations, weed and insect pressure is reduced because pest lifecycles are interrupted.
- When frost seeding in February or March the freeze-thaw patterns of Michigan help to break the seed coat of clover and thus favors germination.
- Rye is a good nitrogen scavenger, acting as storage for the next cash crop.

Issues in this rotation

- The four-way cover crop mix needs to be handled with care. Some of the seed has a hard seed coat, meaning it can return as a volunteer. Mr. Stuckey tries to combat this problem by growing row crops so they can be easily cultivated.
- This rotation is energy, time, equipment, and work intensive, but adds considerable biomass to the soil.

Year	Season	Crop/Cover crop
Y1	Winter	
	Spring	Short season vegetable (e.g. snap beans)
	Summer	
	Fall	Wheat
Y2	Winter	
	Spring	Clover (med. red or MI mammoth)
	Summer	
	Fall	
Y3	Winter	
	Spring	
	Summer	
	Fall	
Y4	Winter	
	Spring	Soybeans
	Summer	
	Fall	Rye (Wheeler)
Y5	Winter	
	Spring	Corn
	Summer	Clover crop mixture (mammoth clover, ryegrass, oilseed radish and hairy vetch)
	Fall	
Y6	Winter	
	Spring	Navy beans
	Summer	
	Fall	Cereal rye and perennial ryegrass

= harvest = winter kill = incorporated = mowed

Other notes

- To the clover stubble, manure, compost, and/or mineral supplements can be applied before chisel plowing to cover nutrients, control weeds, and reduce some of the clover for the following crop (this is especially helpful when MI mammoth clover was grown). The harvest date determines how much of this can be accomplished.
- An optional fallow year after the 6th year of the rotation would allow the soil and soil dwelling organisms to rest.

Chapter 2

Cover Crop Systems

Authors: Karen Renner and Erin Taylor

Contributors: Dale Mutch, Todd Martin, Abram Bicksler, Dan Brainard, Martin Entz, Stuart Grandy, Tim Harrigan, John Masiunas, Mathieu Ngouajio, Sieg Snapp

In the previous bulletin "Integrated Weed Management: One Year's Seeding …" cover crops were discussed on pages 21 – 25. In this chapter we build on what was previously written and discuss some of the questions asked by the farmers that reviewed the IWM bulletin.

Benefits of cover crops

The potential benefits of cover crops in cropping systems are numerous. These benefits include improved soil structure and enhanced soil quality, less soil erosion and protection of water quality, a reduction in commercial fertilizer costs, and suppression of weeds. Weed suppression occurs by several means.

Cover crops reduce light reaching the soil surface

Sunlight warms the soil which triggers seed of many weed species to germinate. Cover crops reduce the amount of sunlight reaching the soil surface. Once cover crops are established, it is difficult for weeds to get started.

Cover crops release chemicals that inhibit the germination and growth of small weed seedlings

When cover crops are killed—either with herbicides, crimping, or incorporation into the soil—chemicals are released from the cover crop residues as they decompose. These chemicals can be toxic to germinating seed and weed seedlings. This is called allelopathy. The chemicals released from the cover crop residues are usually short-lived in the soil because soil microorganisms use these compounds as an energy source. The suppression of weeds by the allelochemicals released from the cover crop residues may only last a short time but this is often enough time for the planted crop to get ahead of the weeds.

Some cover crops act as biofumigants

Biofumigants are organisms that release volatile chemicals, which can result the suppression of diseases and pests. Brassica cover crops are sometimes referred to as biofumigants and the process of incorporating their green residue in the soil for pest and disease management is known as biofumigation. Brassica seed meal can also produce volitile chemicals (see detail box, next page), therefore soil can be amended with seed meal as another biofumigation strategy. Members of the Brassica family that are used as biofumigant cover crops include: oilseed radish, mustards, rapeseed, turnips, canola, etc.

Figure 1. Brassica cover crops, like oilseed radish contain glucosinolates. Todd Martin

Pathogens that can be suppressed by biofumigant cover crops include: *Verticillium* wilt and silver scurf in potato, *Pythium*, *Fusarium*, and *Rhizoctonia* root rots in many crops, *Pythium* in lettuce, pink root in onion, *Aphanomyces*, *Pythium*, *Rhizoctonia*, and *Fusarium* root rot in peas, and cavity spot and *Fusarium* in carrot.

In general, healthy roots are observed when crops are grown in rotation with a Brassica cover crop as long as the cover crop is provided sufficient moisture and nutrients and sufficient biomass is produced (i.e. > 4,000 lbs. per acre) (Snapp et al. 2006).

Brassicas and glucosinolates

Brassica species and other members of the Brassicaceae family (i.e. mustard family) contain glucosinolates in their tissue (Figure 1). Glucosinolates are secondary metabolites used by plants to defend themselves against biotic and abiotic stresses. They are also the compounds responsible for the ‘hot’ taste of mustard and the sulphur-like smell associated with cooking plants in the Brassica family. In their normal form, glucosinolates are not toxic to microorganisms. However, once plant tissue is damaged by cultivation, mowing, etc. the glucosinolates combine with enzymes which change them into a number of volatile chemicals (i.e. isothiocyanates (ITCs), thiocyanates, and nitriles) that are toxic to pests such as plant feeding insects, nematodes, weeds, and fungi. ITCs are similar to the active ingredient used in commercial fumigants like metam-sodium (Sectagon 42). The amount and type of glucosinolates produced depends on the plant species and is usually optimized by maximizing plant biomass production.

Cover crops improve soil health and crop growth

Cover crops (green manure crops) that are plowed into the soil are beneficial to the microorganisms that live in the soil. One study in western Canada compared the microbial community in fields with a crop rotation of wheat followed by tilled fallow to that of a “green fallow (GF) – wheat (W)” system (Biederbeck et al. 2005). The four GF legumes were black lentil, Tangier flatpea, chickling vetch and field pea. These green manure crops were grown to full bloom and then incorporated with a tandem disk. When the top 4 inches of soil was analyzed in the sixth year of the study (i.e. 15 months after the most recent legume GF had been turned under), bacteria numbers increased by 385% and filamentous fungi 210% compared to the wheat–till fallow soil samples. The biologically active carbon and nitrogen increased from 1.6 and 2.0% in wheat–till fallow to an average of 2.4 and 3.5% in GF–W. Microbes are not the only soil organisms that benefit from cover crops.

“Do not plant Mammoth red clover as it can take over a small grain crop.” – Dave Campbell

Many studies have shown that the diversity and overall activity of microarthropods, such as collembolans and mites, are increased by cover crops. Indeed, we could consider that populations of many of the soil organisms that benefit Michigan farmers – e.g. earthworms, ground beetles, and predacious nematodes – increase in diversified crop rotations that include cover crops.

Scientists are very excited about the effects of cover crops on soil biology but what do they mean for growers? For starters, the changes in fungal and bacterial populations improve soil structure. Diverse crop residue inputs increase microbial populations and the production of polysaccharides and fungal hyphae, which cement individual soil particles into aggregates. These aggregates increase water holding capacity, drainage, and soil organic matter concentrations. Furthermore, the release of plant nutrients from soil organic matter is accelerated by microbes and their interactions with larger soil organisms. The supply of plant-available nitrogen would decrease if mites, collembolans, predacious nematodes and other organisms were removed from soils. Unfortunately, this happens in many soils where cover crops are not used and the only way to replace this lost nitrogen is by increasing fertilizer rates. Producers are often in the difficult position of having to replace the services provided by soil organisms, such as building soil tilth and improving nutrient supplies, with costly inputs. Cover crops can reverse this trend; they can improve soil health and, ultimately, production and profits.

Nitrogen availability from various cover crops

All plants contain nitrogen (N) in the leaves, stems and roots and leguminous plants are capable of producing additional nitrogen through nodulation. When a cover crop is killed, this nitrogen is released and the N becomes available to microorganisms and crop and weed plants for growth. Cover crops vary in how much nitrogen they contribute back to the soil so the N credit given for each cover crop varies. Table 1 shows the N credits for many common cover crops.

Table 1. Cost, growth rate, weed suppressive ability, seeding rate and nitrogen credits for popular cover crops grown in the Midwest.

Cost
A = least expensive
B = moderate
C = most expensive

Growth rate
A = fast
B = medium
C = slow

Weed suppression
A = highest
B = medium
C = lowest

	Cost	Growth rate	Weed suppression[2]	Drilled seeding rate (lb/A)[1]	N credit (lb/A)[1-3]
Red clover	A	C	A*	8 – 10	70 – 150
Crimson clover	B	B	B	15 – 20	70 – 130
Oats	A	A	A	80 – 110	—
Hairy vetch	C	B	B*	15 – 20	90 – 200
Sweet clover	A	C	B*	6 – 10	90 – 120
Cowpeas	B	A	B	30 – 90	100 – 150
Field peas‡	B	A	B	60 – 80	70 – 150
Turnips/ Forage rape	B	B	B	5 – 10	—
Oriental mustard	C	A	C	5 – 12	30 – 120[4]
Oilseed radish	C	A	A	8 – 13	50 – 200[4]
Buckwheat	B	A	A	48 – 70	—
Cereal rye	A	A	A	60 – 120	—
Winter wheat	A	B	A	60 – 120	—
Winter barley	A	B	A	50 – 100	—
Triticale	A	A	A	60 – 120	—
Annual ryegrass	B	B	B	10 – 20	—
White clover	B	C	A*	3 – 9	80 – 200
Sorghum-sudangrass	A	A	A	35	—

*These cover crops take longer to establish, however they provide good to moderate weed control once established.
[1]Total nitrogen from plant. These figures vary based on plant density and dry matter; the greater the plant density and dry matter, the greater the N credit.
[2]"Managing Cover Crops Profitably." 2007 (Sustainable Agriculture Network Handbook Series, BK. 9).
[3]Grass and non-legume broadleaf cover crops will recycle available N; however this uptake is based on N residual in the soil and other environmental factors.
[4]Nitrogen scavenger, not likely to immobilize nitrogen like grass species.
‡Also known as Austrian winter peas (black peas), Canadian field peas (spring peas).

Cover crop choices

New ideas for cover crop monocultures

Oilseed radish

Oilseed radish is a part of the Brassica family (Figure 2). It is a good cover crop to use if soil is compacted and in need of aeration. The large taproot on oilseed radish, along with the other roots that sprout from the taproot, will winterkill, leaving behind crop residues and pore space. Weed control with a fall oilseed radish cover crop surpasses that of a hairy vetch, crimson clover or soybean cover crop perhaps by means of allelopathy. Oilseed radish is an excellent nitrogen scavenger and is also thought to acidify the soil around the root, which increases the availability of phosphorus (Ngouajio and Mutch 2004).

Oilseed radish controls weeds more effectively than other cover crops because of its ability to produce abundant biomass in a short amount of time, creating a canopy that blocks out light from weeds. Following wheat and snap beans in Michigan, oilseed radish has shown the greatest reduction in weed biomass when compared with other cover crops such as hairy vetch, oats, and clover (Figures 3 and 4).

Figure 2. Oilseed radish interseeded into corn. Erin Taylor

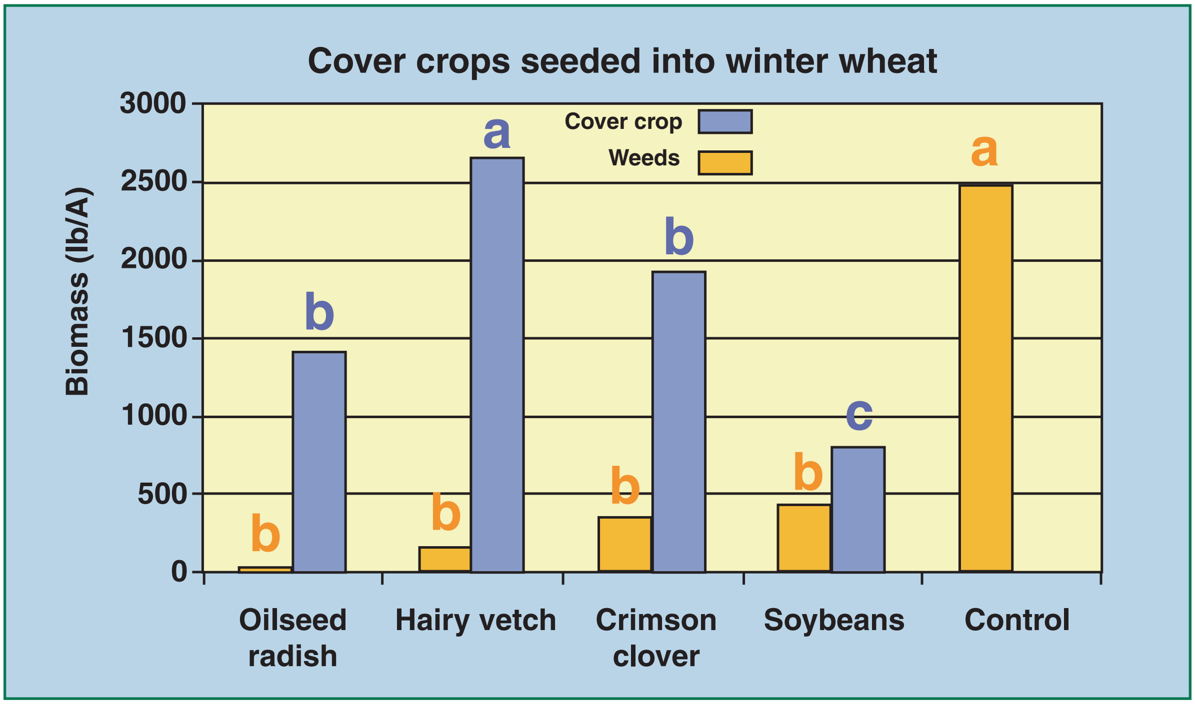


Figure 3. Cover crops seeded into winter wheat suppress weeds. LSD @ 0.05 weeds-570, cover crops-540. Please note that soybeans should be avoided in the presence of soybean cyst nematode. Source: Mutch and Martin, Kellogg Biological Station, Michigan State University.

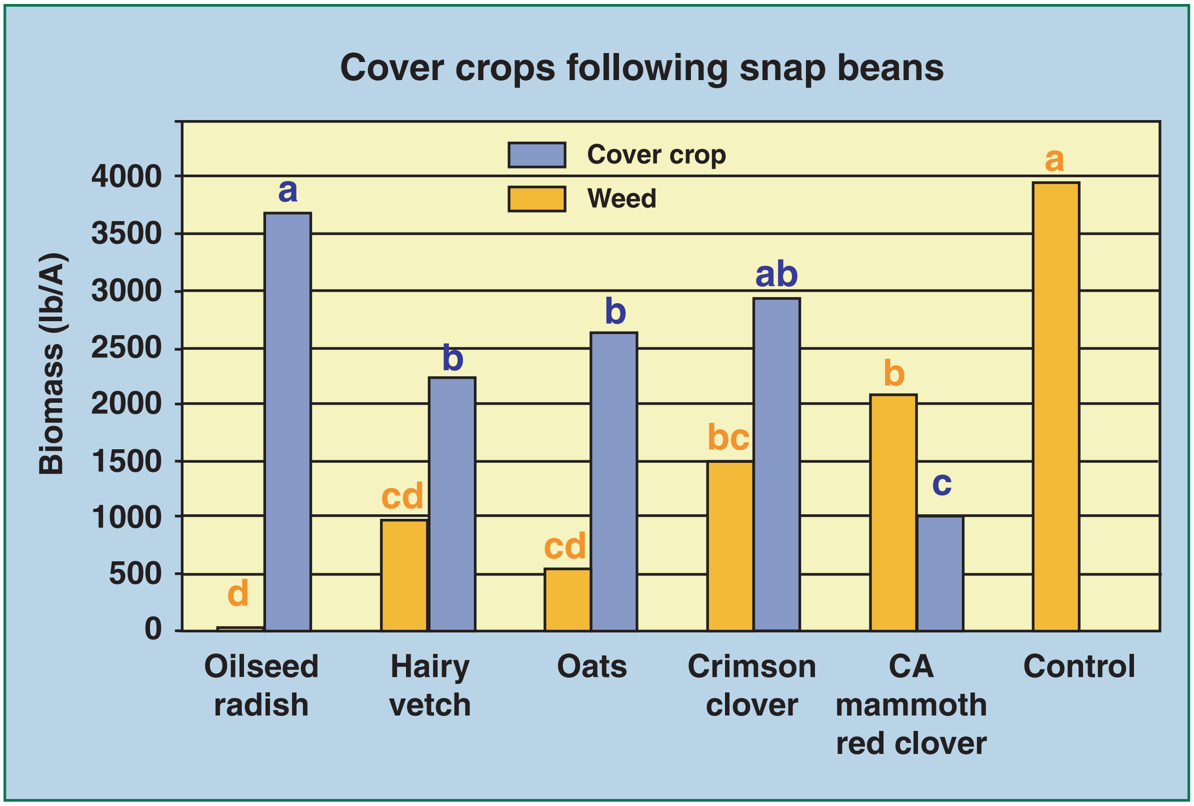


Figure 4. Cover crops following snap beans suppress weeds. LSD @ 0.05 weeds-990, cover crops-1020. Source: Mutch and Martin, Kellogg Biological Station, Michigan State University.

Figure 5. Chickling vetch whole plant (left) and flowers (right). Christine Mason

Chickling vetch

Chickling vetch (a.k.a. grasspea) was bred in Canada (Figure 5). This vetch germinates in cold soils (colder than pea or oats) and tolerates frost. It can be planted early in the spring or in late summer to early fall. Chickling vetch grows well in poor soils, preferring an alkaline pH, and it is somewhat drought tolerant in the spring. Chickling vetch nodulates well but if you have never grown chickling vetch you must inoculate (Figure 6). At the Standard Process Farm in Wisconsin, they inoculate every time they plant chickling vetch and double the rate of inoculum when planting to a new field. They plant the vetch in early spring at 50 lbs. per acre when grown in monoculture and at 30 lbs. per acre when grown with oats (or sometimes oats and buckwheat). The seeds of chickling vetch are known to be toxic to livestock and can cause future weed problems. Mow and/or till the first or second week of bloom to prevent seed set.

Figure 6. Inoculation ensures the formation of nitrogen-fixing root nodules. Christine Mason

"If there has never been vetch in the field inoculate at double the rate. We inoculate every year, so that may be part of our success." – Christine Mason

"Chickling vetch fills an early season void for us. It will germinate at a slightly cooler temperature than oats, so we can get started as close to April 1st as possible and have it worked in nice and early." – Christine Mason

"We plant chickling vetch after early corn harvest." – Tom Miller

Oriental mus-

Figure 7. Oriental mustard. Todd Martin

Figure 8. Buckwheat. Todd Martin

tard

Oriental mustard (a.k.a. brown or Indian mustard, *Brassica juncea*) is a member of the Brassica family (Figure 7). Like other Brassicas it can be planted as a spring or fall cover crop. And, it can be used as a biofumigant cover crop as discussed in the "Benefits of Cover Crops" section above. Oriental mustard emerges quickly and a monoculture planting can cover the ground with growth in as little as 4 to 5 weeks, helping to prevent weed infestations. At the time of incorporation (or winter kill) oriental mustard biomass can reach between 2,000 to 5,000 lbs. per acre in Michigan. Actual biomass potential around the North Central region depends on planting time, precipitation, and other environmental conditions. Mustard seeds have a hard seed coat and can remain in the soil seed bank for several years. Therefore oriental mustard should be incorporated into the soil when flowers first start to bloom to avoid seed production and volunteer plants in future years.

Buckwheat

Buckwheat is a summer annual plant that can be grown as a cash crop and a cover crop (Figure 8). With its short lifecycle (i.e. maturity in 70 to 90 days) buckwheat can fit as a cover crop into several rotation scenarios from late spring to early fall. Buckwheat can produce 2 to 3 tons per acre of dry biomass within 6 to 8 weeks after planting, which shades out emerging weeds. When buckwheat is incorporated into the soil the emergence and growth of several weed species, including pigweed species and shepherd's-purse is suppressed (Kumar et al. 2008). After incorporation, buckwheat residues breakdown quickly and help improve soil tilth. Additionally, buckwheat attracts beneficial insects when flowering and is known to be a phosphorus and micronutrient scavenger. Shortfalls of buckwheat include its poor performance under drought conditions and its potential to return as a volunteer if seed is produced and not harvested (Figure 9). Do not let buckwheat go to seed in the field.

Figure 9. Volunteer buckwheat in soybeans. Erin Taylor

Figure 10. Sorghum-sudangrass. Erin Taylor

Sorghum-sudangrass

Sorghum-sudangrass (a.k.a. sudex) is a hybrid between a forage sorghum and sudangrass that can be planted as a cover crop in late spring or summer (Figure 10). This grass species can grow to heights of 5 to 12 feet, resulting in biomasses that surpass other covers. Sorghum-sudangrass can also be mown during the season to increase aboveground and belowground biomass production. The increase in root mass helps aerate the subsoil. This grass cover crop achieves weed suppression through competition and allelopathy. Sorghum-sudangrass does not survive cool temperatures.

Cover crop mixtures

Mixtures of two or more cover crops have several potential advantages relative to either cover crop grown alone. Mixtures reduce risks associated with variable weather conditions, or variable soil moisture and nutrient status within a field. If pests or environmental stresses restrict growth of one cover crop species in a mix, complementary cover crops can fill the gap. Fewer gaps in cover crop stands result in fewer opportunities for weeds to gain a foothold. Even in uniform fields, complementary mixtures fill different niches, reducing opportunities for weeds. Mixtures can also be helpful for establishing cover crops that are relatively weak competitors with weeds, without requiring costly additional weed control measures like herbicides or cultivation.

Grass-legume mixtures are especially valuable for balancing weed suppression and soil improvement objectives at a reasonable cost. Legumes can reduce fertilizer costs through N-fixation, but many legume cover crops have expensive seeds, are slow to establish, and are poor weed competitors. In contrast, grasses are generally both better at suppressing weeds and less expensive than legumes. Therefore, substituting some grasses for legumes often improves weed suppression while reducing seed costs. Grass-legume mixtures can also improve the efficiency of legume N-fixation. For example, N-fixation per cowpea plant more than doubled when grown in combination with Japanese millet (Brainard, Bellinder and Drinkwater, unpublished). However, grass-legume combinations must be chosen carefully. In the same study, mixtures of either cowpea or soybean with sorghum-sudangrass resulted in good weed suppression, but also suppression of the legumes due to vigorous growth and shading of the legumes by sorghum-sudangrass.

Some promising mixtures

For mid-summer cover crop plantings, cowpeas (Red Ripper or Iron Clay) have performed well in combination with summer grasses including pearl millet, German millet and Japanese millet (Figure 11). Oats and peas are a proven combination for early spring or late summer plantings. In late summer they can produce substantial biomass and nitrogen before winter-kill, leaving a manageable residue in the spring (Figure 12). Winter rye and hairy vetch are a reliable combination for fall plantings (Figure 13). In addition to the benefits described above, this combination is thought to improve overwinter survival of vetch, and reduce harmful allelopathic effects of rye on subsequent crops.

"It's really important to get good soil to seed contact when planting cover crops, especially with small seeds." – Dave Campbell

Figure 11. "Red Ripper" cowpea and Japanese millet. Dan Brainard

"Long periods of rain can delay the timing when you get in the field to manage your cover crops properly." – Richard Baranski

Figure 12. Oats and field peas. Dan Brainard

Figure 13. Rye and hairy vetch. Todd Martin

"If you can frost seed with a light snow cover, late in the winter, you will probably get more seed to germinate than if you wait later when the moisture is gone." – Dave Campbell

Several new early flowering, winter-hardy hairy vetch varieties developed at USDA Beltsville, including "Purple Bounty" and "Purple Prosperity" are being tested for compatibility with winter rye, and may expand the already strong potential of this combination. However, hairy vetch can become a formidable weed problem in perennial crops like asparagus or winter grains, so hairy vetch should be avoided on farms with either of these crops in their rotation. Many combinations involving relay intercropping of shade-tolerant clovers have proven successful, and are described elsewhere in this chapter.

Living mulches

When two or more crops are grown together in the field, it is referred to as intercropping (Figure 14). Intercropping works well when the two crops have complementary growth patterns and nutrient needs. Examples of intercropping include: overseeding clover into a cereal crop (relay cropping), planting soybeans and corn in alternating patterns across a field (strip cropping) and alternating rows of plants in gardens and small plot areas. Fields with two crops seeded

Figure 14. Rye interseeded into corn. Erin Taylor

at the same time (e.g. peas and oats) are examples of mixed intercropping.

If another plant competes with a crop for moisture, nutrients, or light, it is considered a weed. Can a farmer have living mulch in a crop and not have a risk of yield loss? It is very challenging to successfully establish living mulch and not reduce crop yield. Red clover as an interseeded cover crop into a small grain such as wheat is a well-known example. It works in part because red clover can tolerate shade and it does not grow much during the spring (it is planted into a small grain usually in March as a frost-seeding) (Figure 15).

Figure 15. Frost seeding clover. Todd Martin

Most of the clover growth occurs in the summer after wheat is harvested (Figure 16). There is evidence of approximately 5 to 10% yield reductions in small grains in some years where red clover was underseeded. This yield loss is primarily due to water competition; in many years there is no yield reduction. There are considerable long-term advantages to relay cropping with red clover in terms of weed suppression, improved soil organic matter build up, and nitrogen contributions to subsequent cash crops.

Figure 16. Medium red clover growing through wheat stubble at Lily Lake Organic Farm in Maple Park, IL. Erin Taylor

In irrigated crops, opportunities for intercropping cover crops without yield reductions are expanded. For example, irrigated fall Brassica crops including broccoli and kale can be undersown during cultivation operations with winter rye or hairy vetch 2 to 3 weeks after transplanting without yield losses (Brainard and Bellinder 2004) (Figure 17). The winter covers are left following harvest to take up excess nitrogen and suppress winter annual weeds. However, weed suppression benefits during Brassica crop growth are usually minimal compared to cultivation alone. The presence of these cover crops in the main crop can also restrict weed management options (e.g. herbicide choices), resulting in weed escapes that can produce large amounts of seed.

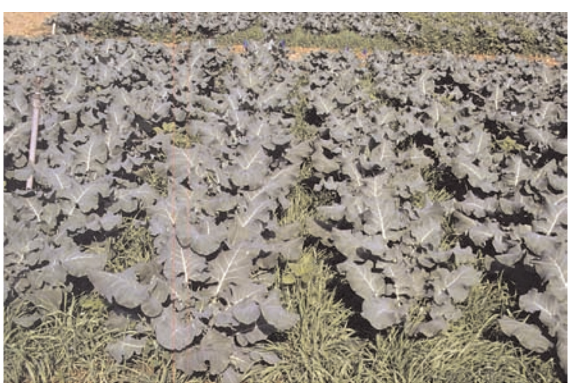


Figure 17. Winter rye intercropped with fall broccoli. Dan Brainard

Eric and Anne Nordell have been practicing intercropping for many years at Beech Grove Farm, their fresh market vegetable farm in Pennsylvania. They interseed a single row of cover crops between 32-inch vegetable rows (Figure 18). This practice protects the soil

Figure 18. Onions interseeded with hairy vetch at Beech Grove Farm. Eric Nordell

from wind and water erosion during the growing season (which is particularly important on their contour strips). For winter annual covers such as hairy vetch and rye, intercropping provides soil protection during the winter months also. Examples of interseeding on their farm include:

- Hairy vetch seeded one month after onions or leeks
- Rye interseeded into late season vegetables (e.g. broccoli, kale, cabbage, etc.)
- Yellow blossom sweetclover overseeded (broadcast) or buckwheat interseeded into early season vegetables

They prevent hairy vetch from climbing up the onions and leeks and interfering with harvest by running a disc hiller (or coulter) along the edges of the crop row, killing the in-row vetch and preserving the vetch vines between the rows.

Sometimes instead of planting the cover crop into the crop they do the reverse and plant the crop into the cover crop. For example, they direct plant garlic into live oats and peas in the fall. In the spring when the garlic is actively growing it is surrounded by the winter-killed oat and pea mulch which reduces weed competition, provides a source of nitrogen, and retains soil moisture.

An on-farm trial was conducted in 2007 and 2008 in Alma, MI to measure corn yield and weed densities in corn grown alone and corn grown with an intercrop of hairy vetch, oilseed radish, ryegrass, and medium red clover. Results from this study can be found on page 95.

"It is more difficult to get good seed soil contact when planting into a killed cover crop. Clumping of the killed cover crop can lead to stand gaps in the crop you are trying to plant." – Oval Myers

Other intercropping ideas include:

- Clover seeded into corn at last cultivation
- Winter cereal rye seeded (drill or broadcast) into 30-inch row soybeans
- Barley planted into onions or carrots – a suggestion from WI grower, Corey Kincaid

Seeding dates and rates

Planting times and rates differ for cover crops just as they do for cash crops (Table 2). Summer annual cover crops such as buckwheat and sorghum-sudangrass need to be planted during the warm months. On the other hand, cold tolerant cover crops like hairy vetch and the clovers have a larger planting window.

Table 2. Seeding timing of various cover crops.

	April	May	June	July	Aug	Sept	Oct	Nov
Red clover								
Crimson clover								
Spring barley								
Oats								
Hairy vetch								
Chickling vetch								
Sweet clover								
Cowpeas								
Field peas‡								
Turnips/Forage rape								
Oriental mustard								
Oilseed radish								
Buckwheat								
Cereal rye								
Winter wheat								
Winter barley								
Triticale								
Annual ryegrass								
White clover								
Sorghum-sudangrass								

‡Also known as Austrian winter peas (black peas), Canadian field peas (spring peas).

Figure 19. Cover crop seed being broadcast from a small plane, courtesy of Al and Mike Schiffer of Ovid, MI. Arnold Walling

Seeding rates for each crop vary based on method of planting, climate, and soil fertility. Cover crop seed can be broadcast by ground or air, drilled, or planted in rows. Different circumstances require different planting methods. For example, if you are planting into a standing cash crop such as corn, cover crop seed will need to be broadcast to avoid damage to the cash crop (Figure 19).

If no crop is present a cover crop could be seeded by any of the listed means. Each of the planting methods (and the presence or absence of a crop or other cover crop) influence seeding rate. Climate and fertility will affect cover crop vigor. In situations with adequate moisture, temperatures, and fertility, a low seeding rate may be enough to achieve desired levels of competition with weeds (Figure 20). When these factors are not ideal, increasing the cover crop seeding rate may help achieve desired competition levels and adequate cover crop biomass. More information on cover crop seeding rates can be found in "Managing Cover Crops Profitably" (see References section).

"Seed size varies, so pay attention to that when setting seeding rates." – Dave Campbell

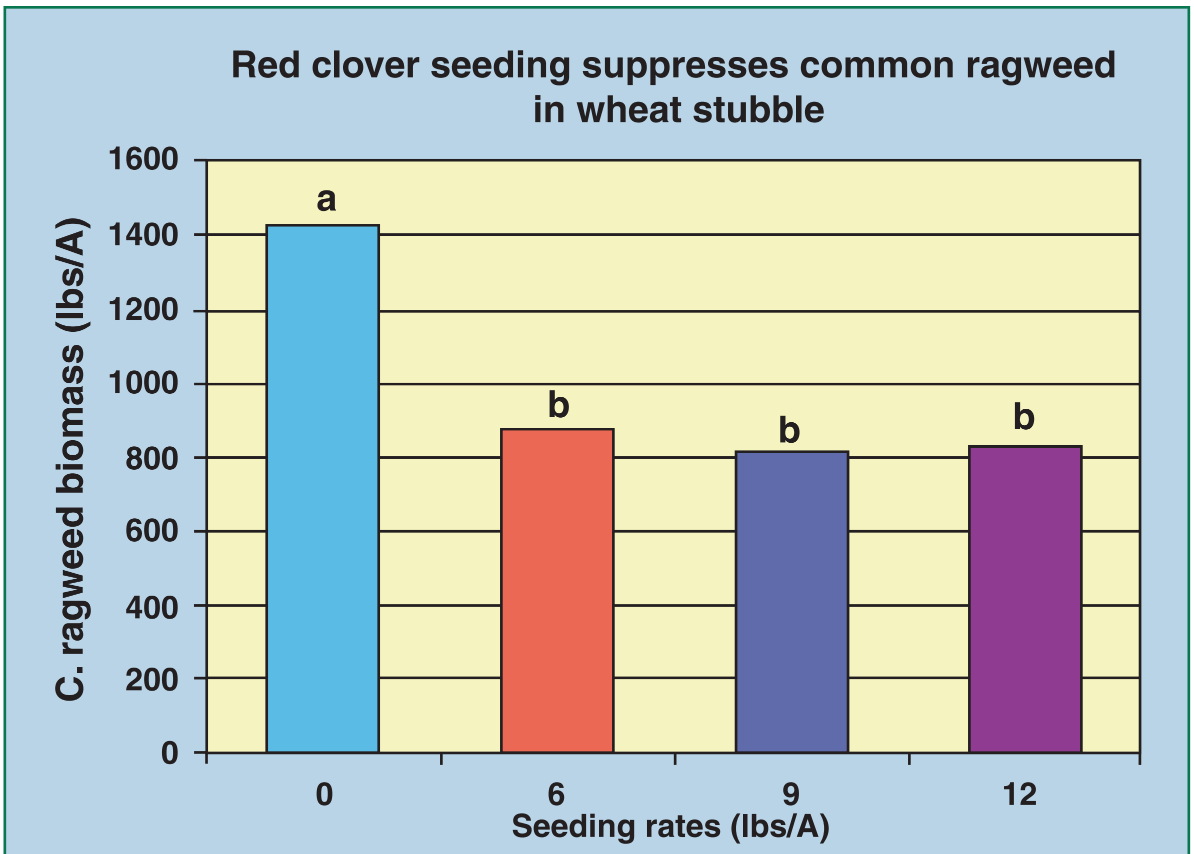


Figure 20. Seeding red clover at 6, 9 and 12 lbs. per acre suppresses common ragweed which is a common weed in wheat stubble in Michigan. The recommended seeding rate for red clover is 8 to 10 lbs. per acre; lower seeding rates in this year still provided ragweed suppression. Source: Mutch and Martin, Kellogg Biological Station, Michigan State University.

"We frost seed with intermediate red clover or June clover usually the first week of March as long as the snow is less than 3 inches deep. We seed at 10 to 12 lbs. per acre if we are thinking of taking a cutting for feed. Most farmers seed at 8 to 10 lbs. per acre. In a good year, we will have red clover about 8 to 10 inches tall the first of August after wheat harvest. A 'good year' equals a lot of timely rainfall. Under these conditions there would be 80 to 100 lbs. per acre of N credits gained before plowdown. If you seed after wheat harvest you would not have enough clover biomass to feed in the seeding year." –
Farmer using red clover

Figure 21. Cover crop seed is added directly to the manure slurry in the slurry tank. Bypass flow from the pto-driven pump provides seed agitation and mixing. Tim Harrigan

Seeding cover crops with liquid manure

Establishment of a cover crop in the fall into compacted soil with little moisture or into small grain stubble such as after wheat is a challenge. A new land application process —manure slurry-enriched seeding—has been in development at Michigan State University since 2003. Manure slurry-enriched seeding combines low-disturbance aeration tillage, manure application, and the seeding of cover crops in one efficient operation (Figure 21). Low-disturbance aeration tillage creates an absorptive surface and improves infiltration in untilled ground while conserving crop residues. In the same pass, the cover crop seed with the manure slurry is delivered through drop-tubes behind each set of aeration tines. To ensure even distribution of the cover crop seed, the seed-slurry mixture is passed through a hydraulically driven rotating chopper/distributor in the tank; excess pump capacity provides bypass flow for mixing. Once applied, the manure slurry carries the seed to protected seeding micro-sites in soil cracks and fissures, or between large soil aggregates. The slurry quickly infiltrates the soil, minimizing volatile nitrogen losses and the loose, absorptive soil surface prevents soil erosion and phosphorus runoff. Soon a cover crop emerges, capturing nutrients and forming a vegetative barrier to overland flow and weed emergence.

This new process builds soil quality by reducing tillage intensity and adding organic inputs—manure and cover crops. Generally, there are fewer cover crop plants per acre—often only 30 to 70% of a conventional seeding—but biomass yield per acre is similar because individual plant biomass is three to six times greater with slurry seeding. Slurry seeding with dairy and swine manure has produced excellent stands of wheat and cereal rye after corn silage, and excellent stands of forage rape, forage turnips, oats, oil seed radish and oriental mustard after a small grain in mid-August. Slurry seeding has been used to successfully improve the yield and botanical diversity of pastures and hay ground with late summer applications of red clover, ladino clover, orchard grass and festulolium (i.e. fescue x ryegrass hybrid).

In 2005 a study was conducted at the Kellogg Biological Station to compare cover crop biomass production and weed biomass using slurry seeding versus no-till seeding of the cover crop. Annual ryegrass, oilseed radish, and oriental mustard all produced more biomass when seeded with manure (Figures 22 to 24). On the other hand, crimson clover growth and weed suppresiveness was reduced with slurry seeding. Generally weed biomass was low except when manure was applied without a cover crop, in which case the weed biomass was more than 1,000 lbs. per acre.

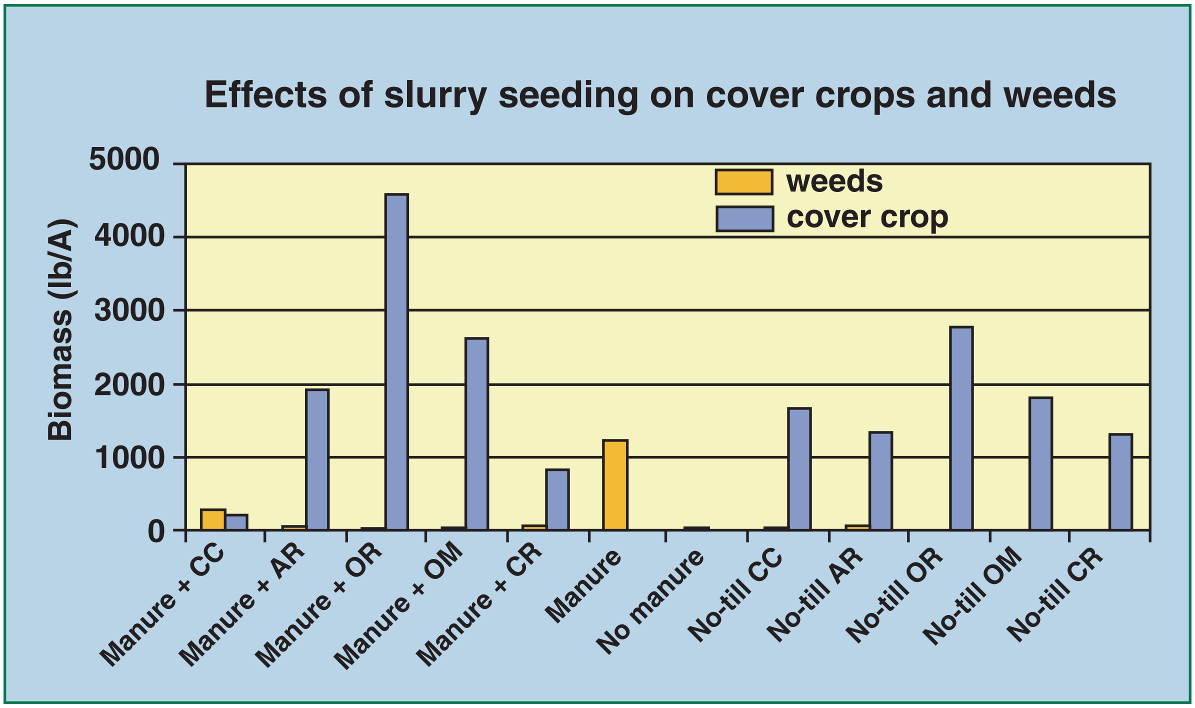


Figure 22. Effect of slurry seeding versus no-till seeding cover crops on biomass production and weed biomass. CC = crimson clover, AR = annual ryegrass, OR = oilseed radish, OM = oriental mustard, CR = cereal rye. Source: Mutch and Martin, Kellogg Biological Station, Michigan State University.

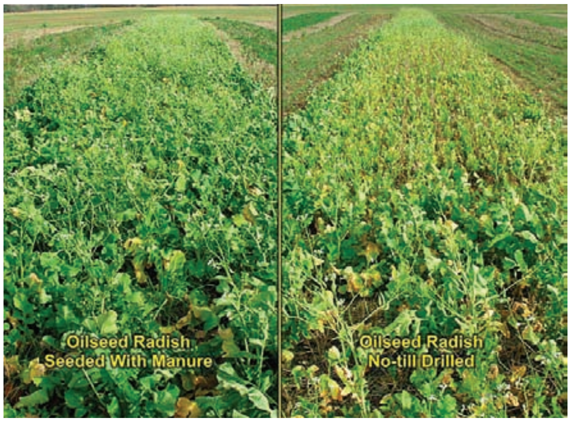


Figure 23. Effect of seeding method on oilseed radish. Todd Martin

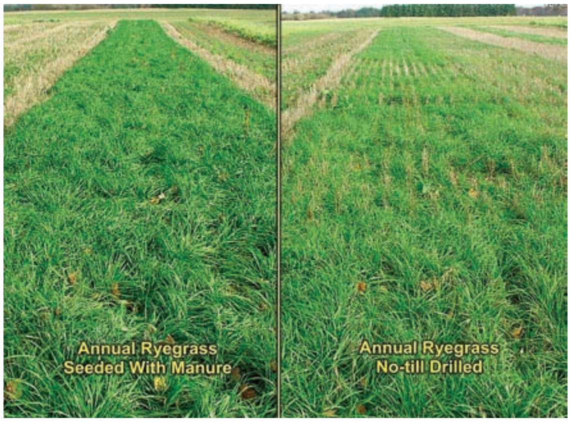


Figure 24. Effect of seeding method on annual ryegrass. Todd Martin

Controlling cover crops

Many cover crops, such as the Brassicas, will be killed by cold winter temperatures (Figure 25). However, cold tolerant crops, such as rye and hairy vetch, need to be controlled in the spring prior to planting the cash crop. Cover crops can be killed using tillage, herbicides or in some cases using a roller-crimper implement (Table 3).

More thoughts on managing rye

- Rye is an inexpensive cover crop to seed (Figure 26).
- Rye protects the soil from erosion and takes up nutrients in the soil and holds the nutrients in the rooting zone until the rye is killed.
- In a wet year rye is a tricky cover crop to manage because of its rapid growth in the spring.
- In a dry year rye can aggressively use water in the soil resulting in dry soil conditions. So in a dry spring some farmers suggest managing rye early. Other farmers feel that the moisture rye takes from the soil can be returned

"Incorporate or plow under a cover crop of rye earlier in the spring if dry weather persists since rye can take up much soil moisture." – Dave Campbell

Table 3. Cover crop management strategies.				
Cover crop	**Winter kill**	**Tillage – timing or size of cover crop**	**Herbicide**	**Roller/crimper**
Red clover	No	2 to 4 weeks before planting	2,4-D ester + Glyphosate	Not recommended
Crimson clover	No	2 to 4 weeks before planting	2,4-D ester + Glyphosate	Not recommended
Alfalfa	No	2 to 4 weeks before planting	2,4-D ester + Glyphosate	Not recommended
Hairy vetch	No	2 to 4 weeks before planting	2,4-D ester + Glyphosate	Not recommended
Oilseed radish	Yes	—	—	—
Oriental mustard	Yes	—	—	—
Buckwheat	Yes	—	—	—
Field pea (Austrian pea)	Yes	—	—	—
Cereal rye	No	9 to 12 inches	Glyphosate	Soft dough stage
Wheat	No	9 to 12 inches	Glyphosate	Soft dough stage
Oats	Yes	—	—	—

"Winter rye is a good choice if it gets too late in the fall to plant anything else." – Tom Miller

Figure 25. Sugar beets being planted into winter-killed oriental mustard. Erin Taylor

by mulching the rye on the soil surface to preserve soil moisture.

- Crimp rye at the soft dough stage.
- Apply herbicides when rye is 9 to 12 inches tall.

More thoughts on managing red clover

"Make sure red clover is disked before the bloom stage or you will lose nitrogen." – Dave Brinker

Mowing

- When you clip and remove red clover, it stimulates regrowth. If there are reasonable growing conditions in the fall/spring, the N accrued will be the same with or without mowing.
- If there is a weed problem in the red clover, mow it down to about 4 to 6 inches in mid to late August.
- If there is not a weed problem, there is no need to mow in the fall.

Spraying

- 2,4-D ester plus glyphosate provides excellent control of red clover in the spring.
- Glyphosate alone in the fall works better than spraying glyphosate alone in the spring.

Tillage control

- Moldboard plow in either fall or spring gives excellent control (100%).
- One pass chisel in fall will reduce clover stand but you may need one or possibly two reduced tillage operations in the spring. Rating = very good (>90% control).
- Chisel in the spring once early (two weeks before planting), follow up with one or two field operations (field cultivator). Rating = very good (>90% control).
- Incorporate 8 to 10 inches in the soil.
- Be aware of seed corn maggot. Allow at least two weeks between incorporation and planting the next crop and be aware of seed corn maggots life cycle when incorporating green manure crops.

Figure 26. Rye. Todd Martin

Controlling cover crops in no-till

Tillage is an important tool for weed management and cover crop termination and incorporation in organic systems. However, tillage reduces soil organic matter and can be detrimental to soil structure over time. Alternative methods of managing cover crops would reduce tillage on farms and improve soil quality.

Figure 27. Crimping rye and planting soybeans in one pass Kellogg Biological Station. Todd Martin

In the first IWM bulletin we discussed controlling cover crops by winter kill, mowing or mulching, incorporating the residues into the soil, applying herbicide, or by using a roller-crimper. A roller-crimper crimps the cover crop stems, leaving behind a green mulch that dies in several weeks (Figure 27). Recent research with the roller-crimper has yielded the following results:

The University of Manitoba began experimenting with a roller-crimper (blade roller) in the summer of 2007 (Martens, J. T. and M. Entz 2008). Their roller consisted of a drum with protruding blades attached lengthwise along the drum, and the drum was filled with water for weight (additional weights were

Figure 28. Pea and oat mixture after crimping. Mark Entz

added on top of the roller). They evaluated the effectiveness of the roller at killing an oat/pea green manure crop in late July. Pea and oat stems were “crimped” by the blades every 8 inches or so, and the crop showed signs of wilting within about 15 minutes of rolling (Figure 28). One week later, the rolled oat/pea crop was predominantly dead, although later in summer there was some pea regrowth. Some of the plots were rolled a second time.

In a second trial, green manure crops (lentil, pea/oat, chickling vetch, faba bean, hairy vetch) were terminated with various combinations of rolling and tillage to see if an optimum number of rolling operations and tillage operations could be determined. Preliminary results indicate that rolling can substitute for at least two tillage operations, though the level of weed infestation dictated when tillage was finally required in green manure systems. Under low weed conditions, no tillage was needed and wheat was direct seeded into the pea/oat mulch in May the following year. Among the green manures studied, only hairy vetch appeared somewhat resistant to rolling, especially if it was rolled in the early flowering period (Figure 29). The more mature the hairy vetch, the easier it appeared to be killed with the roller.

Figure 29. Hairy vetch and barley mixture after crimping. The hairy vetch was crimped a second time after this photo. Mark Entz

“Make sure the cover crop you are thinking of planting is not a host for something negative to the next crop”. – Pat Sheridan

“Using cover crops is a learning experience; adjustments are usually necessary as conditions vary from year to year and field to field.” – John Simmons

Figure 30. Hairy vetch and rye mixture immediately after crimping. Todd Martin

Figure 31. Soybeans growing through a mat of crimped rye. Todd Martin

"In spring work red clover down to secure the N and control the weeds." – Amos Adams

At Michigan State University the roller-crimper has been studied to control rye, hairy vetch, and a combination of the two cover crops prior to no-till soybean planting (Figure 30). The cover crops were crimped in the spring and then soybeans were no-till planted immediately into the residues (Figure 31). In all treatments the cover crops were successfully controlled; rye was in the soft dough stage and hairy vetch was flowering at the time of crimping. After planting more weeds began to emerge through the hairy vetch residue compared with the rye alone and the rye plus hairy vetch treatments. As a result, the hairy vetch alone treatments yielded significantly lower than the rye alone and rye plus hairy vetch treatments (Figure 32).

Research with roller-crimpers is ongoing at many locations in the Midwest. The most effective time for crimping needs to be determined for various green manure crops. Furthermore, the cover crop residue laying on the soil surface may influence planting

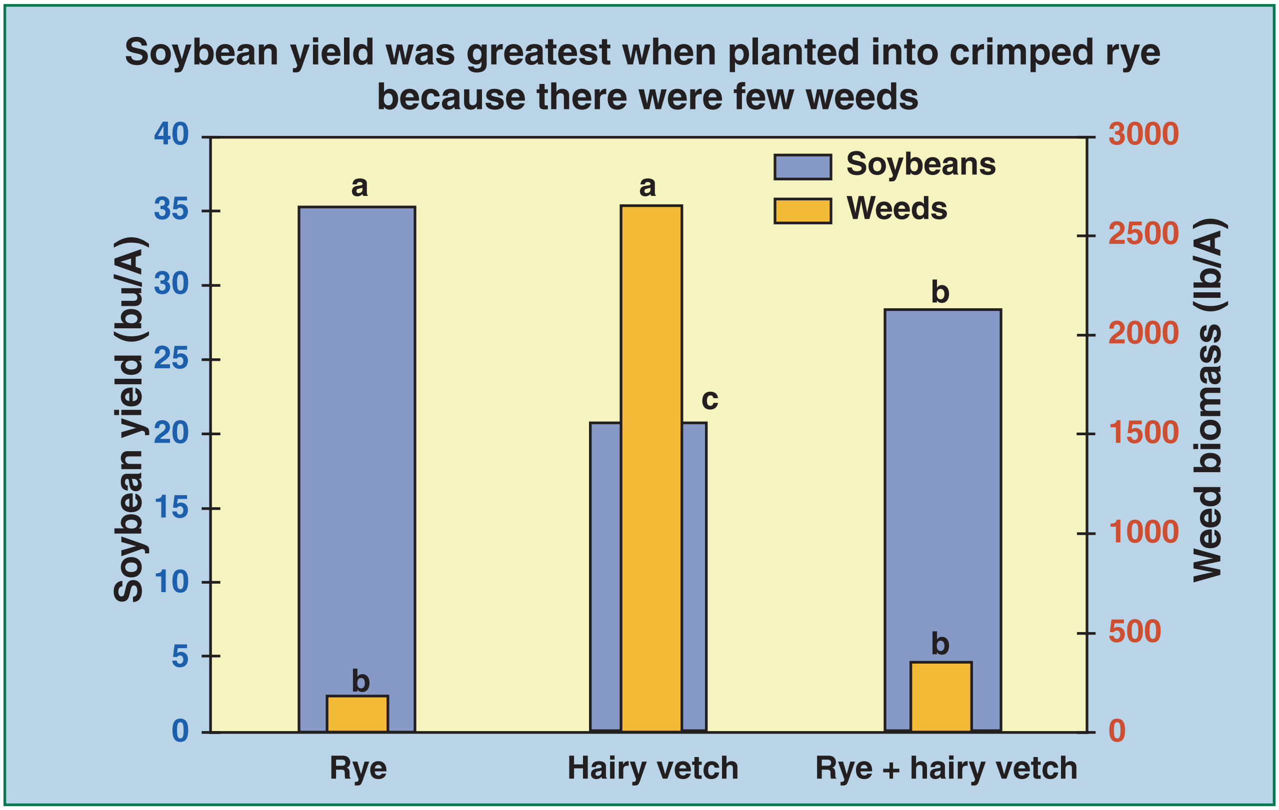


Figure 32. Yield and fall weed biomass for organic soybeans planted into crimped rye, hairy vetch, or a combination of the two cover crops. Different letters among yields or weed biomass indicate a significant difference among treatments. Source: Mutch and Martin, Kellogg Biological Station, Michigan State University.

(seed-soil contact), nitrogen availability throughout the growing season, pest management issues, and water conservation. Currently the University of Manitoba is investigating how rolling affects N release from the green manure crops and Michigan State University is examining the effect of rye variety on crimping success.

Challenges with crimping rye

- Rye maturity dictates planting date, which results in planting later than most farmers want to.
- Maturing rye can rapidly dry out soils making planting difficult.
- Late fall seeding of rye may cause thin stands, which allows for cool season weeds to germinate in these fields.
- An adequate N supply is needed for vigorous rye growth. Our experience shows healthy rye rolls/crimps better than stressed rye.

Harvesting cover crops for seed

Harvesting cover crops for seed is an option for growers. The grower still has the nitrogen and carbon benefits of the cover crop in the field but also has seed to use in future years and a potential profit when selling the seed. In years with adequate moisture Michigan growers are able to harvest intercropped clover seed in the fall two to three months after wheat harvest. Buckwheat is another example of a cover crop that can be planted and harvested for seed, particularly if you are taking a field out of production for a year to combat weed problems. Most cover crops can be harvested using a combine by making adjustments specific to the seed being harvested. Any seed that is not harvested will germinate in future years and may become a weed problem in the desired crop. Do not allow cover crops to go to seed in a field unless a harvest is planned and volunteers in the future can be managed.

Cover crop issues

Cover crop impact on cash crop establishment

Cover crops require sufficient time for residues to decay before crops can be seeded after a cover crop. About three weeks is a typical time frame farmers should allow between incorporating a cover crop and planting a cash crop. If a cash crop is planted earlier in the field, poor seedling establishment may result because the cover crop residues have not yet decayed and can interfere with planting operations and the biological decomposition process can enhance disease in crop seedlings. Allelochemicals released from the decaying cover crop can also inhibit germination and seedling growth during the first few weeks after cover crop incorporation. The size of the cash crop seed is important. If the cash crop seed is sufficiently large (e.g. potato tuber piece or soybean seed), there are few problems from cover crop residue decay.

Cover crops use soil moisture to grow. This can be an advantage in terms of suppressing annual weeds through competition that reduces water available to support weed germination and growth. However, competition for soil moisture is a very important consideration in spring-seeded, non-irrigated cash crop production. If the cover crop uses some of the spring moisture needed for the cash crop, yield loss can occur. Cover crops build up soil organic matter and water infiltration which promote growth of subsequent cash crops, but water management must be taken into consideration when deciding whether to plant a cover crop (Mutch and Snapp 2003)

"Chisel plow red clover late in the fall rather than trying to plow the following spring if you have tight or wet soils." – Dave Campbell

"Rye becomes easier to kill when headed out. Moisture used can be offset by moisture preserved by the rye mulch. We like to kill the cover crop six weeks before planting to guarantee enough soil moisture for unirrigated vegetables." – Eric Nordell

Table 4. Beneficial and detrimental insects associated with cover crops.

Cover crop	Beneficial insects	Insect pests
Buckwheat	parasitic wasps[b] ladybugs tachinid and hover flies lacewings minute pirate bugs insidious flower bugs	tarnished plant bugs aphids[c]
Clover[a]	predatory and parasitic wasps big-eye bugs minute pirate bugs ladybugs tachinid flies aphid midges bees	spider mites flower thrips[d] clover root curculio tarnished plant bugs
Hairy vetch	minute pirate bugs ladybugs big-eyed bugs predatory and parasitic wasps	tarnished plant bugs
Cereals and grasses	ladybugs	aphids thrips leaf hoppers

[a]Varies slightly by species.
[b]Attracted to extra floral nectaries.
[c]Can act as a food source for beneficials.
[d]Can prey on spider mite eggs and provide food for several predatory insects.
Adapted from University of Connecticut IPM (www.hort.uconn.edu/IPM/) and "Managing Cover Crops Profitably."

"In north central PA we've found that seed corn maggot is only a problem in our vegetables after incorporation of an over-wintered cover crop, not a winter killed cover crop." – Eric Nordell

Pests and plant diseases

Just as a cover crop can attract beneficial insects to a field and suppress certain diseases it can also attract pests and increase other diseases (Table 4). As one example, the seed corn maggot can become a problem for corn and soybean crops following the incorporation of a cover crop. As the cover crop decays it can attract egg-laying flies and create a moist, nutrient-rich environment that is favorable for developing larvae. As another example, hairy vetch can increase existing *Pythium* and *Rhizoctonia* populations compared to leaving the field fallow over winter, causing problems for subsequent cash crops (Rothrock et al. 1995). The best way to avoid a buildup of pest problems is to diversify and rotate the types of cover crops used.

"The best way to avoid a buildup of pest problems is to diversify and rotate the types of cover crops used." –Anonymous

Volunteers and crop seed contaminates

If a cover crop is allowed to produce seed there is a chance of it coming back as a weed in the crop that follows. Hairy vetch, oriental mustard, and chickling vetch were three cover crop examples mentioned earlier in this chapter. If these cover crops go to seed they can become weed problems in future years. (Figure 33).

Crop contamination problems can also occur with Brassicas, such as oriental mustard and oilseed radish, and buckwheat which rapidly produce seed. As soon as a Brassica or buckwheat cover crop flowers a management plan must be implemented to stop seed production. Even immature green Brassica seed can be viable in some species and can return as a weed later in the crop rotation and/or contaminate grain seed.

Figure 33. Hairy vetch seed is a black sphere with a hard seed coat (pictured among Mammoth red clover, ryegrass and oilseed radish) Erin Taylor

Conclusion

The short- and long-term effects of cover crop integration into a crop rotation require careful consideration. It is important to remember that a good cover crop is by definition a good weed: it establishes rapidly and grows fast, often suppressing other plants through allelopathy and competition. Timing is an essential aspect of managing cover crops. It will require careful time management to plant a cover crop into a 'vacant' window, manage the cover crop so it does not go to seed, and manage cover crop residues so as to allow sufficient time for subsequent cash crop operations. There are many exciting cover crop options that can markedly reduce weed germination while enhancing soil and crop health – but they all require 'biologically smart' farming, and experimentation to determine where they might fit on your farm. Ultimately the choice of cover crop, where and when (or if) to plant a cover crop will depend on economics. and the extent to which a farmer determines benefits outweigh potential problems.

"You have to know what you want to do ahead of time so that you can manage potential volunteer issues. It can be a great cover crop." (Referring to buckwheat) – Dave Campbell

Canada thistle suppression with cover crops

By Abram Bicksler and John Masiunas

University of Illinois

What makes Canada thistle a problem weed?

It can rapidly spread (Figure 34), forms dense patches, suppresses growth of crops, and is poorly controlled using standard approaches. Tillage can cut the roots into small pieces, spreading patches; tillage equipment can also carry root pieces to new sites. Mowing must start at thistle flowering and be repeated numerous times. Common winter annual cover crops (i.e. cereal rye, hairy vetch, wheat) are not present during the most susceptible growth stages of Canada thistle.

Figure 34. Excavated Canada thistle root system. Abram Bicksler

What are the key factors to controlling Canada thistle?

It is a long-day plant; flowering and seed production starts in July. Shoots must be killed to prevent seed production (Figure 35). Emerging Canada thistle seedlings will not survive shading from other plants. Grow competitive crops that rapidly close canopy. Thistle plants store sugars and other carbohydrates in their roots. The stored carbohydrates allow thistles to overwinter and emerge in the spring or after disturbance. Established Canada thistle is best controlled after emergence at the beginning of flowering (in July), when root carbohydrate reserves are lowest. Depletion of these reserves will reduce the thistles' fitness and ability to re-grow from roots.

Figure 35. Canada thistle ready to disperse seed into the wind. Abram Bicksler

Our approach to Canada thistle management combined tillage, summer annual cover crops (Figures 36 and 37), and mowing. Unmowed sudangrass alone or combined with cowpea (70:30 Sudangrass:cowpea) produced 6.2 and 5.8 tons per acre of dry biomass, respectively. Sudangrass alone or combined with cowpea caused a 96% reduction in thistle density in the first growing season. One year after planting sudangrass, thistle numbers were still below 10% of the beginning densities. Neither buckwheat nor a summer fallow adequately suppressed Canada thistle. Mowing is less important for reducing thistle fitness and survival compared to the sudangrass cover crop.

We recommend disking thistle-infested areas several times during the spring to eliminate emerged thistle, prevent flowering, cut roots into small pieces, and create a uniform seed-bed for sudangrass. In early June, drill a sterile sudangrass hybrid such as "Special Effort" at 55 lbs. per acre into the freshly prepared seedbed. The thick sudangrass canopy can shade out Canada thistle. Sudangrass may be mowed when 4 to 6 feet tall to manage cover crop growth and prevent flowering of surviving Canada thistle (Figure 38). Use a flail mower to create a surface mulch and encourage sudangrass regrowth and tillering (Figure 39). In late fall or early spring, incorporate the grass residue into the soil and plant a competitive crop. Use cultivation, hand-removal, or spot treatment with herbicides or flaming to control any remaining Canada thistle.

"I would absolutely consider using sudangrass for future Canada thistle suppression." – Dave Campbell

"Sudangrass works so much better than anything else I've tried to control Canada thistle." – Dave Campbell

Figure 36. Sudangrass and buckwheat strips. **Abram Bicksler**

Figure 37. Untreated strip full of Canada thistle bordered by buckwheat and sudangrass. **Abram Bicksler**

Figure 38. Flail mower used to mow cover crop treatments. **Abram Bicksler**

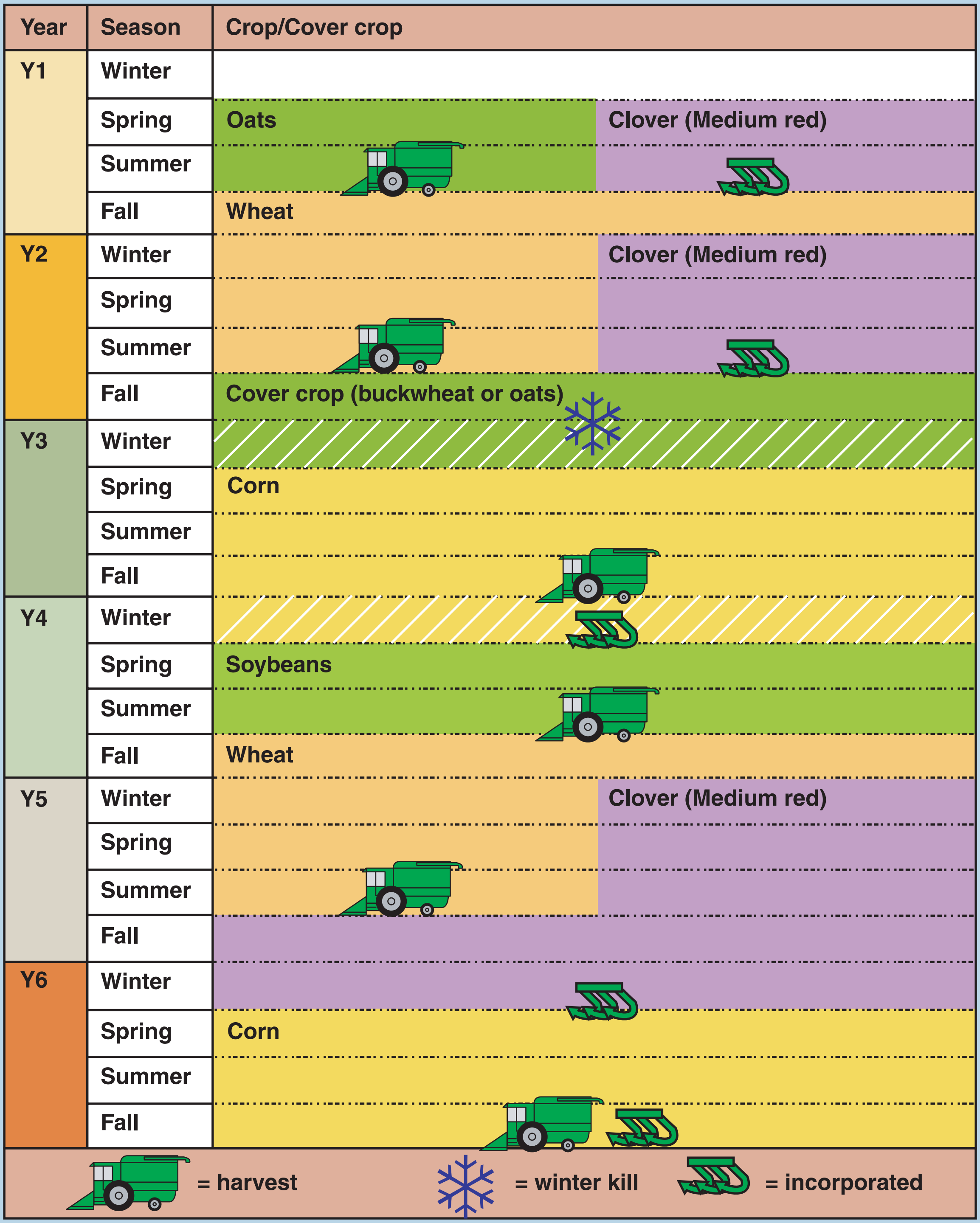
Figure 39. Sudangrass mulch and regrowth following mowing. **Abram Bicksler**

Farmer profile

Dave Campbell, Maple Park, IL

Dave Campbell has been farming organically for 20 years on 224 acres in northern Illinois. In that time he has experimented with several different cover crops (Figure 16).

Rotation



"Make sure you have a reliable source when it comes to determining seeding rates. Why over do it? But you don't want to skimp either." – Dave Campbell

"Usually it is best to try things out on a small scale. It can save you from making big mistakes." – Dave Campbell

Average precipitation (inches):											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2	2.5	3	3.5	4	4.5	4	4	3	2.5	2	2

Cover crop experiences

Legumes

- **Medium red clover**
  Seeds annually in different fields around the farm.

  Frost seeds into wheat.

  - Medium red clover frost seeded 8 to 10 lbs per acre.
  - Chisel plows clover in the fall or plows during late summer after wheat harvest if planting another cover crop such as oats or buckwheat.

  Spring plants with oats.

  - Medium red clover with oats in spring 8 to 10 lbs. per acre.

- **Mammoth red clover**
  Usually too aggressive when growing with oats, especially in a wet year.

- **Sweet clover**
  Hard seed can be a volunteer problem in future crops, especially in hay or small grains.

- **Alfalfa**
  When sown the year before corn is planted alfalfa results in high amounts of nitrogen available to the corn.

- **Hairy vetch**
  Excellent nitrogen source for corn, but it can cause a volunteer problem, especially in small grains, for many years.

  Buyers will usually refuse a grain crop contaminated with hairy vetch seed.

- **Cowpea**
  Tried once in a research plot to determine effectiveness in controlling Canada thistle. It did not work as well as hoped due to poor germination.

- **Chickling vetch**
  Germinated very well, but due to hot and dry weather in September growth was stunted.

  Seed can be more costly than other legume seed.

"Try to make sure there is no contamination of the cover crop seed with weed seed." – Dave Campbell

Non-legumes

- **Sorghum-sudangrass and sudangrass hybrids**
  Plants in late June.

  Used for Canada thistle suppression project (see On-farm Trials, Chapter 7).

  Would absolutely use it again if Canada thistle became a problem.

  Plans to plant it on the edges of a field where the thistle is bad to stop it from spreading; only sacrificing a couple acres of production.

- **Oats**
  Used as a cash crop in the spring. Intercropped with medium red clover at planting.

  Used as strictly a cover crop in the fall (planted in late August to late September).

  - Does not contribute N to the system (not a concern if a legume crop is to follow).
  - Extracts phosphorus from the soil.
  - Emerges quickly with one decent rain.

  Benefits

  - Planting in early September versus late September allows for more growth (more than 1 foot tall).
  - Stays green most of the winter.
  - Greatly minimizes soil erosion.
  - Feeds soil life and holds extra nutrients.
  - Leaves behind very little residue and requires less tillage before a spring planted crop.

- **Rye**
  Can extract a lot of moisture from the soil if left too long into the spring.

  Excellent allelopathic effect for spring planted crops.

  Use rye as a cover crop before soybeans, but not corn (to avoid two grass crops in a row).

- **Wheat**
  Used as a cash crop on a regular basis.

- **Buckwheat**
  Plants in mid August so it does not go to seed and become a problem.

  Covers the ground quickly.

  Buckwheat does an excellent job in creating good soil tilth, which results in less germination of weed seeds.

  Buckwheat (crop)– ~60 lbs. per acre (1.25 bushel).

  Buckwheat (cover crop) – ~75 lbs. per acre.

Cover crop problems

There can be problems planting into a cover crop. As an example, one field was previously half in clover and half in rye. Both cover crops were moldboard plowed and planted on the same days. For a good part of the growing season where the clover had been the beans were bigger, bushier, and healthier. During the season and at harvest, where the rye had been the beans did not look as healthy. However yields from each half appeared to be the same.

He has not noticed any problems related to insects with using cover crops.

Strategy for controlling Canada thistle

Mr. Campbell will mow bad thistle patches and will also have them hand weeded prior to harvest. If a Canada thistle infestation covered 10% of a field his strategy over the next 2 to 3 years would proceed as follows:

Year 1

- Field cultivate 3 to 4 times in the spring/early summer.
- Plant buckwheat in mid-July as a cash crop.
- Plant a rye cover crop in the fall.

Year 2

- Moldboard plow and disk with harrow in the spring
- Field cultivate 2 to 3 times in the spring
- Plant corn or beans (beans allow more time for early season operations)

Year 3 (If thistle is still bad…)

- Plow in the spring, followed by 2 to 3 cultivations.
- Plant a sorghum-sudangrass cover crop in late-June. Since the weed pressure is still high it is worth losing a year of production to bring it under control and avoid future losses.

Cover crop seed sources

- Albert Lea Seed House
  Albert Lea, MN
  www.alseed.com/organic.php
- Welter Seed and Honey Co.
  Onslow, IA
  www.welterseed.co

Cover crop references

- Managing Cover Crops Profitably, 3rd edition. 2007. Sustainable Agriculture Network. Beltsville, MD. pp. 244. Andy Clark editor.
- Weed the Soil, Not the Crop. 2007. Anne and Eric Nordell. Booklet and DVD available by mail order ($10 book, $15 DVD + $3 s&h per item):
  Anne and Eric Nordell
  3410 Rt 184
  Trout Run, PA 17771
- Mustards: A Brassica Cover Crop for Michigan. 2006. Michigan State University Extension bulletin E-2956. S. Snapp, K. Date, K. Cichy, and K. O'Neil. Available at: http://web2.msue.msu.edu/bulletins/Bulletin/PDF/E2956.pdf
- No-till Revolution
  Rodale Institute
  Information available at:
  http;//www.rodaleinstitute.org/no-till_revolution

Chapter 3

Manure and Compost

Author: Karen Renner

If a farm has livestock or spreads manure from livestock farms, will weed problems increase? Will new weed species suddenly emerge in farm fields? Will weeds grow rapidly in manured fields and be more difficult to manage? The answer to these questions lies in three different areas of the livestock system: a) the feed source, b) the type of animal, and c) the manure handling system (Figures 1-3).

Figure 1. Hay silage. Erin Taylor

Figure 2. Piglets. D.W. Rozeboom

Weedy feed sources are a risk

Livestock are fed pelletized feed products, forages and grain. When feed is ground and pelletized, very few weed seeds survive.

Figure 3. In-ground dairy manure lagoon (above) and aboveground swine manure lagoon (below). Erin Taylor

However, the few weed seeds that do survive in the feed pellets may become the start of a new weed problem on the farm. Ideally, there are few weed seeds in forage and grain harvested for livestock feed. However, if weedy forages or grain are bought from another farm operation and fed to livestock, the potential exists for the introduction of new weed species on the farm (Figure 4). One or more common lambsquarters seeds in feed would never be noticed in most farm fields,

Figure 4. Dairy cattle being fed a mixture of corn and hay silage. Erin Taylor

but one or more seeds of a new uncommon species such as annual morningglory in central and eastern Michigan would be an unwelcome sight.

Weedy forages and grains usually contain seeds along with the leaves and stems of the weeds. Some of these weed seeds are non-dormant. They will germinate immediately once they reach the soil. Other weed seeds present in feed are dormant. These seeds will wait to germinate until they are no longer dormant and conditions are right. If this year's feed is weedy, you may be adding new weed seeds to the soil but there may be no difference in weed emergence for one or more years. Because weedy feed can be a problem for more than one year on your farm it is always best to try to use weed-free feed and bedding materials.

"If you are feeding forage from a field with one set of weed species, spread the manure back on that same field so you do not introduce new weed species to your other farm fields." – Oval Myers

What about ensiling (Figure 5)? Does ensiling help with weedy feed? Yes, fermenting feed as silage decreases weed seed viability (viability means a 'living' seed that is capable of germinating at some point in time). In 1937, barnyardgrass and yellow foxtail seed did not germinate after being ensiled for two weeks, and only 4% of the small seeded broadleaf weed redroot pigweed germinated (Tildesley 1937). Common lambsquarters seed was more resistant to ensiling; 34% germinated after two weeks but by four weeks 0% of the seed germinated. More recently, researchers in Alberta, Canada demonstrated that seeds of many weed species do not survive both ensiling and digestion (Blackshaw and Rode 1991). Using a common source of feed they looked at weed survival after ensiling for 8 weeks, rumen digestion of raw material, and ensiling + digestion. The results: 17% of green foxtail seeds survived rumen digestion; all other grass seed was killed. Ensiling alone killed all of the green foxtail, barnyardgrass, foxtail barley, and downy brome seed. Interestingly, less than half of the broadleaf weed seeds were killed by rumen digestion (Figure 6); ensiling destroyed more broadleaf weed seeds (Table 1).

Figure 5. Harvestore silos on a Michigan dairy farm. Erin Taylor

Table 1. Average percentage of viable (alive) seed remaining after fermentation in a silo, rumen digestion or both.

	Ensiling in a silo	Rumen digestion	Silo + rumen digestion
	% viable seed		
Redroot pigweed	6	4	4
C. lambsquarters	3	52	2
Wild buckwheat	30	56	16
Round-leaved mallow	23	57	17
Field pennycress	10	68	10

Adapted from Blackshaw and Rode (1991).

Figure 6. Researchers access the rumen of a cow using a window-like fistula that can be opened and closed. Erin Taylor

Figure 7. The size and seed coat thickness of weed species varies. This can affect how well a weed survives digestion (Clockwise from the top: velvetleaf, giant foxtail, redroot pigweed, giant ragweed, tall morningglory, common milkweed). Erin Taylor

The animal makes a difference

What happens to weed seeds when they are fed to cattle, horses, swine, sheep, and chickens? In 1934, researchers fed seed of velvetleaf, field bindweed, sweet clover, smooth dock, smartweed, wild rose, and pepperweed to livestock (Harmon and Klein 1934). About 25% of the weed seeds fed to cattle and hogs were recovered intact in the manure, and 10 to 12% of the weed seeds were found intact in horse and sheep manure. Chickens destroyed 98% of the weed seeds because of the grinding action of their gizzards. Interestingly, weeds with softer seed coats had greater mortality, e.g. only a few sweet clover, wild rose, and pepperweed seed were capable of germinating and starting new plants after going through the digestive tract of any livestock. Small, hard seeds had the easiest time passing through the animal and being excreted in manure intact and ready to start future weed problems. Common lambsquarters, pigweed species, and smartweed are examples of weeds that have small hard seeds (Figure 7).

Manure handling system

Manure has solid and liquid, inorganic and organic components. The composition of manure varies with the livestock type and age, the livestock feed, and the housing and bedding materials (Table 2). Manure and composted manure enhance soil quality. Applying manure or compost increases soil organic matter in a field. This in turn increases soil aggregate stability and water-holding capacity of the field soil which is beneficial to crop production.

Table 2. N, P and K content of various manures.

Animal type	Total N	NH_4-N	Usable N	P_2O_5	K_2O
	lb/ton				
Hogs	17.8	4.7	7.5	8.5	11.0
Dairy	12.2	2.6	3.7	3.1	10.8
Beef	14.6	1.6	3.4	4.2	12.3
Sheep	14.4	3.4	4.7	4.8	14.5
Dairy goats	21.6	5.8	7.6	5.2	11.5
Composted, cattle	17.2	1.1	5.8	5.2	23.8
Grain-fed veal	15.8	2.7	4.4	3.3	10.2
Horses	10.8	1.6	2.8	2/9	10.6
Rabbits	24.4	2.6	5.6	15.8	13.8
Poultry	47.4	11.0	20.8	20.4	25.3
Layers	34.5	15.4	19.6	15.6	17.0
Pullets	42.0	12.4	20.0	16.6	19.4
Broilers	62.2	3.8	20.9	23.6	34.6
Broiler breeders	39.0	6.6	15.7	26.8	30.3
Turkeys	46.1	16.5	23.7	23.3	24.4

Source: Adapted from Best Management Practices: Manure Management. 2005.

Manure also increases the microbiological activity in the soil, and provides nutrients for crop and weed growth. Fifty percent of the total nitrogen in liquid dairy manure and 30% in solid dairy manure is available to the plant the first year following a spring application.

Figure 8. Liquid manure application using a liquid spreader (above) and dry manure being spread with a box spreader (below). Kevin Shelle

"High rates of manure or compost on the surface favors chick-weed." – Eric Nordell

Manure is a very beneficial resource in crop production systems, yet many farmers are hesitant to apply manure to their fields because they are worried about weeds (Figure 8). Farmers and agronomists speculate that velvetleaf was introduced to New York fields in the 1970s in manure from dairy cattle that were fed corn from the U.S. Midwest that contained velvetleaf seeds (Mt. Pleasant and Schlather 1994). The velvetleaf seed passed through the cows and was spread in manure on the New York farm fields.

"Giant rag-weed loves nutrients from manure." – Ron Heebink

Weed seeds in manure

There are weed seeds in fresh manure. People have been studying this phenomenon for the past 100 years! In 1908, one researcher fed dairy cows seed of 21 weed species and then hauled the manure out to the field and mixed it slightly with the soil (Oswald 1908). He discovered that 13% of the weed seeds germinated. The species that survived the 'trip' through the dairy cows included mallow, common ragweed, jimson-weed, smartweed and dock.

The number of weed seeds in the manure depends on how weedy the feed is and which livestock species produces the manure. Mt. Pleasant and Schlather, two researchers in New York, found on average about 40 weed seeds per pound of manure in their survey of 20 New York dairy farms. If a farmer spread 20 tons of manure per acre this would equal about 40 seeds per square foot. Is this a lot of weed seed? In the north central region of the United States, weed seed numbers in the soil seed bank range from 56 to 14,800 seeds per square foot (Renner et al. 2000). If a field has low weed pressure (few seeds in the seed bank), 40 seeds per square foot is a lot of seed. In a field with a high weed seed bank, this is less than a 1% addition to the seed bank. Therefore the impact of spreading fresh manure on the weed seed bank in a field can be either considerable or negligible. An important question to ask, regardless of the size of the seed bank on the farm field, is what weed species are in the manure? Is it a new weed species in the feed? Is this weed species hard to manage or control? If so, then a few weed seeds per square foot may be a few weed seeds too many.

Manure storage time and weed seed

Curing manure by stockpiling the manure before applying it to crop fields reduces weed seed viability. The number of smooth pigweed and goosegrass seedlings in manure decreased by 65 to 70% when manure was stockpiled for 3 months compared with manure stacked only for one month (Rupende et al. 1998). Temperature increased from 68° F in the unstacked manure to averages of 93 and 108° F in manure stockpiled for three and five months, respectively. The manure stacks were 5 feet in height and 3.3 feet in diameter and were sampled at a depth of slightly over 2 feet below the surface every 30 days. The higher temperatures generated in manure stacks are optimal for microorganisms to decompose weed seed (Figure 9). Furthermore, the ammonia gas and uric acid generated in the manure stack also contribute to weed seed decay.

Figure 9. Dry chicken manure. Erin Taylor

Composted manure: A better handling system?

Composting is an aerobic (oxygen-requiring) biological process that decomposes manure and other organic materials (Figure 10). Composting reduces the odor and volume of manure and results in less material to haul to the field and spread. The organic fraction of the manure is stabilized in the composted manure. The nutrients in the composted manure must be mineralized (converted to organic nutrients by microorganisms) before they are available to the crop and weeds for uptake. That is why compost is considered a slow-release fertilizer.

The most widely used composting method is conventional composting where manure is deposited in windrows. There are many composting guides available that provide detailed information on how to compost. Two are listed below for your reference.

- **Composting Manure and other Organic Residues**. 2006. C. S. Wortmann, C. A. Shapiro, and C. C. Tarkalson. NebGuide Ext. bulletin G1315. pp. 4

  Available at: http://www.ianrpubs.unl.edu/epublic/live/g1315/build/g1315.pdf

- **On-Farm Composting Handbook** (NRAES-54). ©1992 by NRAES (Natural Resource, Agriculture, and Engineering Service). edited by R. Rynk. pp. 186.

  Order at: http://www.nraes.org
  Or by calling: (607) 255-7654

The ideal carbon to nitrogen ratio (C:N) in compost is 25:1 to 30:1. The C:N ratio in manures is quite variable (Table 3).

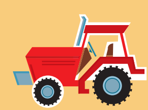
Figure 10. Finished dairy compost. Erin Taylor

Table 3. Carbon to nitrogen ratio for manure from different animals.

Source of manure	Carbon to nitrogen (C:N) ratio
Dairy	8:1 – 30:1
Dairy free stall	13:1
Beef feedlot	10:1 – 20:1
Swine	15:1 – 21:1
Sheep	13:1 – 20:1
Horse	22:1 – 50:1 (w/bedding>30:1)
Chicken	4:1 – 18:1
Broiler litter	12:1 – 15:1

Adapted from two sources: Wortmann et al. 2006 and Rynk 1992.

Many farmers must add another source of carbon such as pen packed manure, bedding, or wood chips to have the correct C:N ratio in the compost. Moisture in the compost should be 50 to 60%. Moisture is maintained at this level during the time of composting so the microorganism populations survive and thrive (propagate) (Figure 10). Air must continue to be introduced into the windrow by mechanical turning or some type of aeration system. Oxygen is added and trapped heat and gases are released when the compost is turned. The oxygen stimulates the aerobic microorganisms to reduce organic materials to a more stable material similar to humus. Compost windrows are turned once or twice a week for the first two to three weeks, and then once a month after that.



"There is no fertilizer that can duplicate manure, but it does increase weed pressure." – Douglas Custer

"Inject the manure and get the nutrients to the crop plants to help them compete with the weeds. Manure makes weeds more competitive unless it is tilled into the soil." – Tom Blanchett

Composting occurs when temperatures in the windrow are 104 to 150° F. Maintaining a temperature of 130° F or more for two weeks kills weed seeds and most plant pathogens and stabilizes the composted material. Windrow turning needs to be more frequent if temperatures exceed 140° F because temperatures above 155° F kill low and medium temperature microorganisms. Composted manure passes through several stages as temperatures increase in the windrow or pile and then slowly decrease as there becomes less carbon to break down (Figure 11). When the pile fails to re-heat after turning, the compost material is biologically stable. The final compost has little to no manure odor left, is fine-textured, low moisture, and contains fewer viable weed seeds.

High temperatures in compost kill weed seeds

Temperatures in most compost piles should be between 130 and 150° F. Cooler temperatures and drier conditions occur in the tops of compost piles due to the semicircular shape of the windrow. The top of the pile is exposed to more ambient conditions and more evaporative drying. Increasing the frequency of turning the compost reduces survival of all weed species, probably as a result of increased temperatures in the windrow. Weed seeds will only survive the composting process if there are localized 'cool spots' caused by inefficient turning of the windrow, or if windblown seeds contaminate the finished compost (Grundy et al. 1998). The time and temperature needed to reduce weed seed viability (kill weed seeds) is the topic of many studies.

Composted manure in California dairies

Cudney et al. (1992) found that composted manure 6 to 8 weeks old from six California dairies contained varying amounts of viable weed seeds including mustard species (21%), yellow foxtail (21%), and barnyardgrass and pigweed species (12%). The number of viable weed seed varied from 18,000 seeds per ton in fresh dairy manure to 300 to 4,000 seeds per ton in manure that had been composted for 6 weeks.

Figure 12. Managing weeds surrounding composting areas prevents the spread of weed seed. Erin Taylor

Keep areas surrounding compost processing and storage sites free of weeds to avoid spreading additional weed seeds in farm fields (Figure 12).

Figure 11. The rate at which compost is turned is related to the internal temperature of the pile. Steve Deming

Composted manure in Texas feedlots

In a Texas A & M study, seeds of barnyardgrass, johnsongrass, pigweed (primarily smooth and some Palmer amaranth), kochia, and field bindweed were composted with beef cattle manure at 24% moisture. Seed of all species except field bindweed were killed with three days or more exposure at 120° F in the compost. Bindweed seed required 7 days at 180° F for all seed to be killed in the compost pile (Wiese et al. 1998) (Figure 13).

Figure 13. Texas beef feedlot. Ben Weinheimer

Composted manure in Alberta, Canada

In Alberta, viability of composted seeds of green foxtail, redroot pigweed, and wild oat was only 2 to 12% after two weeks of composting. After one month, less than 1% of the weed seeds survived, and no seed survived two months of composting. Wild buckwheat seeds were much more resilient to composting; it took two months (50 days) for wild buckwheat viability to be reduced to less than 2%. Round-leaved mallow was another weed species with some tolerance to composting (Larney and Blackshaw 2003).

Table 4 groups weed species into three categories: easy, moderate, and difficult to kill with composting using information gathered from various studies (Egly 1990; Larney and Blackshaw 2003; Thompson et al. 1997). As you can see, the lethal temperature to kill weed seeds in compost varies widely among weed species.

Table 4. Weed species vary in the temperature and duration of the temperature required to make weed seeds nonviable (dead). Weed species are grouped into three categories: easy, moderate and difficult to kill with composting.

Easy 7 days at 130 F	Moderate 14 days at 130 F	Difficult 30 days or more at 145 F
shepherd's-purse	wild proso millet	common groundsel
cleavers	foxtail barley	birdeye speedwell
scentless chamomile	wild oats	round leaved mallow
wild mustard	Canada thistle	common lambsquarters
tansy mustard		spiny sowthistle
barnyardgrass		ladysthumb
green foxtail		
johnsongrass		
downy brome		wild buckwheat*
kochia		field bindweed*
pigweeds		broadleaf dock*

*Most difficult to kill composting; may require warmer temperatures.

Source: Egly 1990; Larney and Blackshaw 2003; Thompson et al. 1997.

What else in the composting process destroys weed seeds?

High temperatures in compost piles are lethal to weed seeds but there are probably other mechanisms that play an important role in reducing weed seed viability.

1) In the early stages of composting, there can be a high concentration of ammonia or pathogens in the compost. High concentrations of ammonia in the compost may reduce weed seed germination due to salt toxicity or osmotic stress.

2) Water-soluble organic compounds that are harmful to weed seeds are formed in immature composts. These phytotoxins may delay or decrease germination of many weed species.

3) Warm temperatures and moist conditions in the compost may interact to relieve weed seed dormancy.

This could promote fatal germination of the weed seeds in the compost.

4) Warm temperatures and moisture coupled with the microorganisms present in the compost may also accelerate weed seed aging and make seeds nonviable.

Composting tip: Plant a cover crop when the composting area is empty to prevent weed growth. The cover crop can then be composted too.

Other types of composting

Biodynamic composting is a special form of composting. Manure is inoculated with pulverized and/or liquid compost preparations, and this facilitates the decomposition of the manure (Zaller 2007). Another type of composting is vermicomposting. In vermicomposting high earthworm densities and soil microorganisms are added to increase manure decomposition and stabilization. Temperatures in vermicomposting do not exceed 95° F to avoid harming the earthworms, and the piles are not turned mechanically. In research by Zaller (2007), seed of broad-leaved dock (a close relative of curly dock) was buried in windrows of regular compost, biodynamic compost, and vermicompost from cattle manure. Weed seed was removed at monthly intervals to test for germination. The maximum temperature reached in the conventional and biodynamic composts was 145° F. The maximum temperature in the vermicompost was 95° F. Germination of dock seed buried for one month in vermicompost was still 48%. Twenty-eight percent germinated in conventional compost, and 18% in the biodynamic compost. After three months, dock seed germination was 22% in vermicompost and 3% in the other two compost treatments. This work suggests that the maximum temperature in compost is important and that additional factors contribute to killing weed seed in compost.

Issues with composting

If composting is so beneficial for weed management, why not compost all manure? The issues with composting include the cost of equipment (a compost turner can cost more than $20,000), the labor to manage the compost, the time and space needed to process the compost, the need to add other carbon materials to the compost, a concern for nutrients and pathogens in leachates and runoff from the compost windrow, the loss of carbon and nitrogen, and the need to have the proper equipment to spread the finished compost. During a three-year Nebraska study as much as 40% of the total beef feedlot manure nitrogen and 60% of the total carbon was lost to the atmosphere during composting. Runoff and leaching losses of sodium and potassium were also high (Wortmann et al. 2006). Compost can be piled on a concrete base, but there will still need to be provisions to contain or control leachate runoff.

There are many excellent publications on manure and compost management (see a few suggested references at the end of this chapter). It may be more desirable to spread manure directly as a nutrient source, but if manure is going to be stored, composting may be a desirable storage alternative.

Figure 14. Anaerobic digesters at a Michigan dairy. **Steven Safferman**

Anaerobic digesters and weed seeds

Anaerobic digesters transform manure into two components: methane gas that can be converted into electricity, and an effluent that differs from raw manure in terms of odor, bacteria, and composition (Figure 14). Temperatures in the anaerobic digester range from 95 to 100° F. Do weed seeds survive the process? Researchers at University of Minnesota compared weed seed survival and germination in the field following rumen digestion only and rumen digestion followed by 20 days storage in manure with or without anaerobic digestion (Katovich et al. 2005). Rumen digestion killed all of the giant foxtail, wild proso millet, and ladysthumb seed. Velvetleaf, common lambsquarters, and pigweed seed survived rumen digestion and germinated in the field. Emergence of these three weed species in the field was not reduced when the seeds were placed in the anaerobic digester or stored in manure for 20 days!

This is in contrast to previous work cited by Minnesota researchers where seed of curly dock, common lambsquarters, pigweed, and barnyardgrass survived anaerobic digestion if placed at a 16-inch depth in the digester but not when placed at a 70-inch depth at the bottom of the tank. Temperatures may have been higher. High temperatures in anaerobic digesters may be one important factor in reducing weed seed viability.

Manure and compost application

Nutrients available to crops from manures and composts are also available to weeds. Placement of the nutrients in the field soil can play an important role in reducing weed emergence and vigor. For example, Petersen (2003) reported that weed N uptake and weed biomass were 50% lower with subsurface-banded compared with surface-broadcast liquid swine manure. Other researchers have also documented lower weed biomass and higher crop yield with injected versus surface-broadcast applied fertilizer or manure. Injecting or harrowing in manure is a standard practice in manure management and reduces the influence of manure on weed growth.

When using a broadcast-type manure spreader, incorporation of the manure is essential to reduce volatilization and runoff and to reduce nutrient concentrations in the top 1 inch of the soil where most weed seeds germinate.

How do you spread compost? Box spreaders usually spread 7 to 12 tons per acre at normal speeds and this is often too much compost. Unlike nitrogen, composting does not eliminate phosphorus and actually concentrates this nutrient. Since phosphorus can be a limiting nutrient for manure application rates it can be problematic to adjust manure box spreaders to a low enough application rate. Slinger spreaders work best for spreading compost more evenly in the field (Figure 15). Remember, the nutrient composition of the compost should determine the amount of compost applied in a field and not the equipment.

Figure 15. Slinger spreader used for spreading manure and compost. Erin Taylor

Weed growth in manured and composted fields: An important consideration

A farmer notices a new patch of actively growing weed seedlings in a recently manured field. Is this occurring because new, viable weed seeds were added to the field in the manure? Did the application and incorporation of the manure trigger the germination of weed species that are sensitive to light? Are weeds flourishing in the field because there are now more nutrients available for crop and weed growth? Did soil quality improve with the manure applications and weeds now have the oxygen, moisture, and nutrients available for germination and growth?

A farmer notices less weed emergence in a composted field compared to a manured field. Why might this occur? Remember that during composting, temperatures become so hot that most weed seeds should be killed. So applying compost should not increase the number of weed seeds in the field.

Compost, manure and other organic materials release nitrogen as they are broken down by microbes and other soil organisms. Because this is a biological process, it occurs over time in synchrony with increasing temperatures during the growing season and demand by crop roots. As inorganic N is produced it is taken up by crop plants. In contrast, systems that rely entirely upon commercial N fertilizer are saturated with inorganic N, particularly early in the season if most of the N is applied at planting. Weeds can exploit this excess N to gain a competitive advantage over the crop early in the growing season (Figure 16).

"Manure keeps ground moist and weeds do well in these conditions. If manure is spread evenly then it works out OK." – Farmer using manure

"Except for starter fertilizer, manure is my only N source for corn on corn. I have not noticed any extra weed control problems where manure was applied with my current [weed management] program." – John Huber

Figure 16. Foxtail emerging with corn. Erin Taylor

It is important that compost and manure are applied to fields at rates based on the nutrient composition of the manure and compost and the crop nutrient needs.

In Wisconsin, researchers looked at weed growth in corn the year following a single manure application to fields at 11 dairy farms (Cook et al. 2007). Manure had not been applied to these fields for at least ten years. Slurry was spread at eight sites and solid manure at three sites. By 7 to 8 weeks following corn planting, weed density was the same in manured and non-manured field plots. All of the farmers weed control practices were highly successful. Would these results be different if more frequent manure applications were made to these fields over time? Since soil organic matter and nutrient availability increases with manure applications over time, would weed growth also increase or would the weed community change? For example, common lambsquarters and common chickweed are nitrophilic (nitrogen-loving) weeds (Figure 17). If nitrogen became more available, would these two weeds increase in dominance in farm fields? In a study in Europe, researchers increased the manure application rate from 9 to 53 tons per acre on limed soil. The density of common lambsquarters, shepherd's-purse, and common chickweed increased 29, 47 and 225% respectively, compared with the weed densities on the non-manure-treated field plots (Ciuberkis 2001). Note that 53 tons per acre of manure is well above what most farmers would be applying! Manure increases both crop and weed growth so the goal of manure applications is to tip the competitive balance to favor crop growth in the production system. Applying manure at or below the rate of nutrients required for the upcoming cropping season results in a manure application rate that is in tune with crop nutrient needs, keeps weed growth in check, and reduces the number of weed seeds being added to the farm field.

Figure 17. Common lambsquarters (left) and common chickweed (right) are both nitrogen-loving weeds. Erin Taylor and Chad Lee

In Iowa, researchers compared corn and weed growth in two soil management systems, designed to provide equivalent amounts of nitrogen to corn. One system included compost and the other system did not. Common waterhemp and velvetleaf height and seed production, as well as waterhemp biomass was greater in the system where compost was included. Interestingly, compost had no effect on giant foxtail height or biomass (Liebman et al. 2004). We know compost supplies nutrients to the soil that weeds as well as crops utilize. Compost may also modify the abundance and diversity of soil microorganisms. These changes in the soil microbial community may also translate into increased growth of some weed species.

In Alberta, researchers compared the growth and competitiveness of weeds in spring and winter wheat crops following application of fresh cattle manure, composted cattle manure, and commercial N fertilizer (Blackshaw 2005; Blackshaw et al. 2005). Manure, compost, or commercial fertilizer was applied for four consecutive years to assess what happened to weeds over time. At the end of the four year experiment the weed seed bank ranking was composted manure = broadcast N fertilizer >fresh manure > banded N fertilizer. This research shows the importance however, of good weed management in manured and composted fields over time.

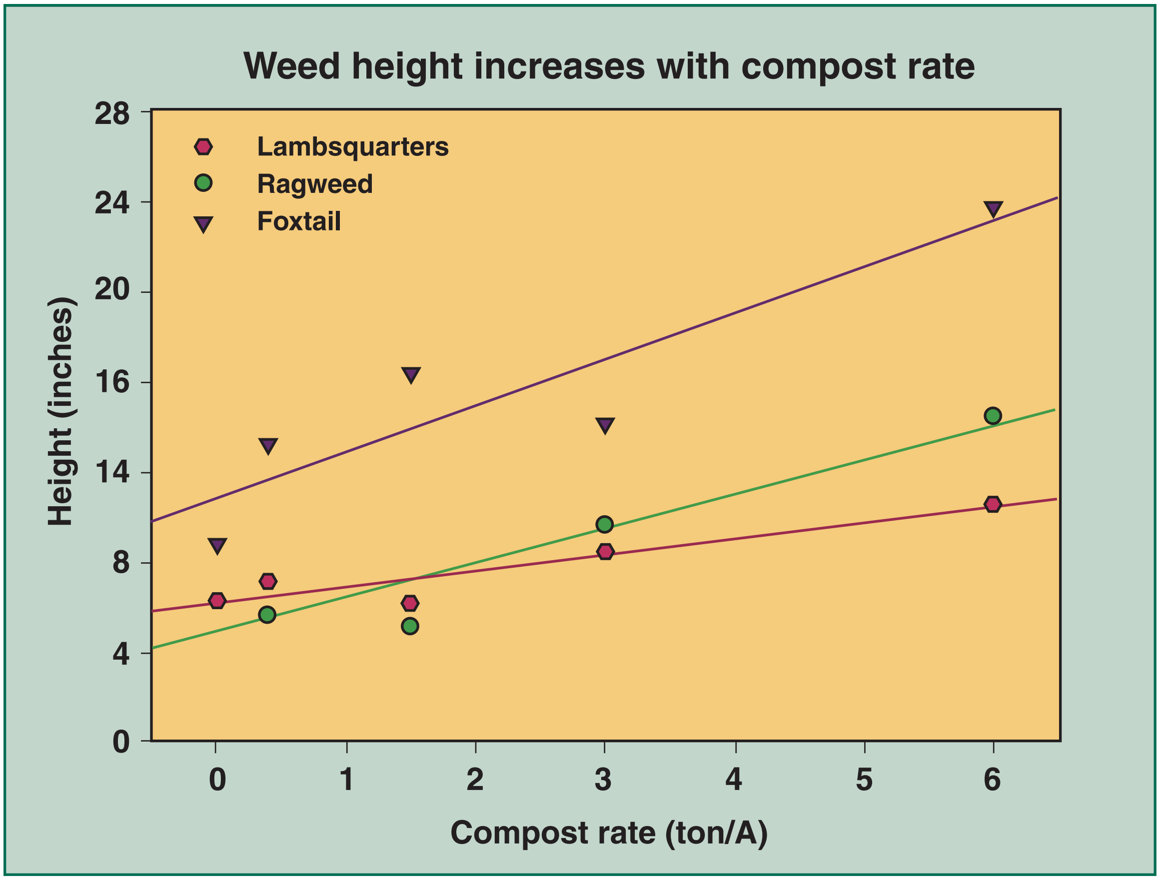


Figure 18. Weeds grew taller in the field as the rate of compost increased.

"How you apply manure makes a big difference. Injected manure is better than broadcast and harrowing improves the crop advantage over the weeds." – Farmer using liquid manure

In a recent study by Mohler and DiTommaso (2007), the height of giant foxtail, common ragweed and common lambsquarters increased significantly in response to the rate of composted chicken manure applied in organic corn (Figure 18). Good weed management by the farmer prevented weeds from becoming abundant enough in this study to reduce yield in any of the crops in the composted treatments.

Manure and compost applications provide many benefits to the soil and to the crop. Managing weeds in manured and composted fields requires timely weed control tactics. Always monitor manured and composted fields for new weed species, especially when livestock feed is brought in from out of the area. Be prepared to manage weeds when needed. Good weed management by the farmer will prevent weeds from competing with the crop, and the crop will benefit from the nutrients and improved soil quality from the manure or compost applications.

Questions

True or False:

Q: Manure should be added to fields to increase soil organic matter and soil fertility.

TRUE: Manure improves soil quality.

Q: Manure adds weed seeds to the soil.

TRUE: If manure contains viable weed seeds then seeds will be added to the field.

Q: Applying manure can introduce new weed problems.

TRUE: If manure contains viable seed of a new weed species not currently found in the field then applying manure can introduce a new weed species.

Q: Composting manure is lethal to most weed seeds.

TRUE: Very few weeds seeds survive composting for two months at 130° F.

Q: Applying manure or compost can increase weed growth over time.

TRUE: Manure is a nutrient source and adding nutrients and improving soil quality can increase weed growth as well as crop growth.

Q: Timely weed management reduces weed problems.

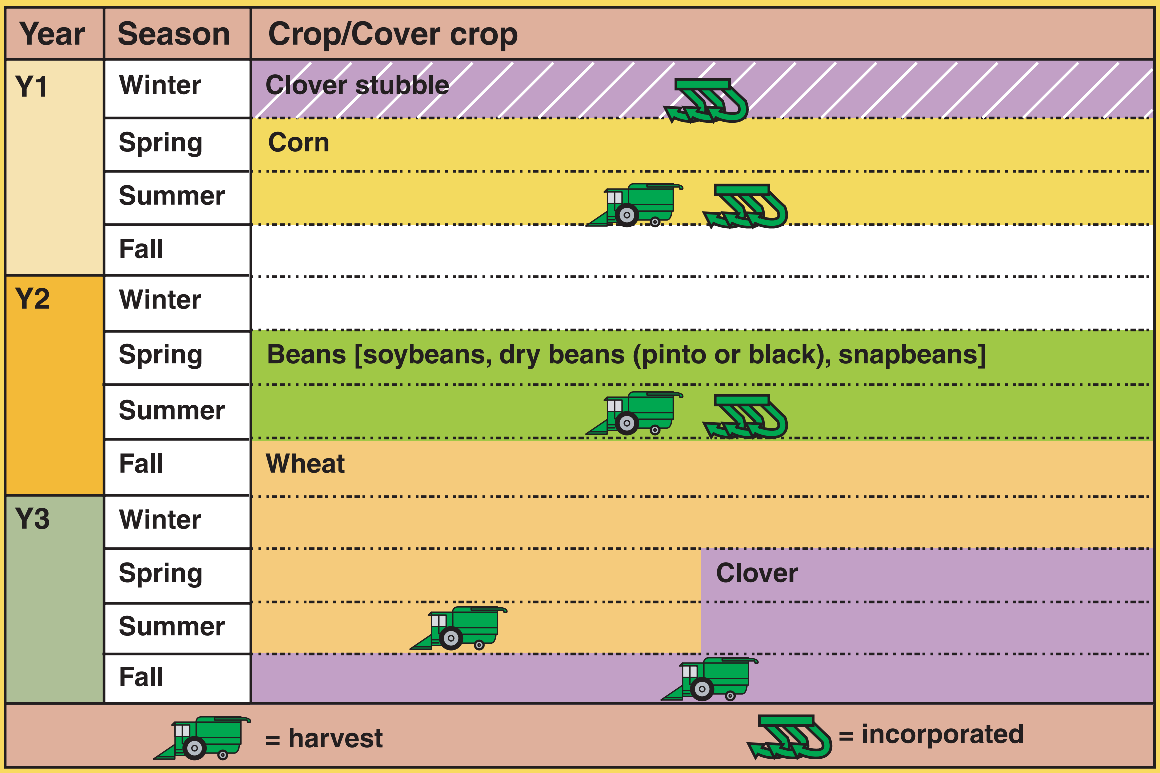
TRUE: Weedy fields can be brought under control by planting competitive crops, having a diverse crop rotation, and controlling weeds when they have just emerged in the field and prior to flowering and seed production. Attention to weed control is important in all crops in all cropping systems.

Farmer profile

Ben Sattelberg

Bay Shore Farms (Unionville, MI)

Rotation



*22-inch rows for corn and beans

Nutrients

In addition to the nitrogen fixing clover cover crop and foliar applications to the beans and hay, the Sattelbergs use a combination of compost and manure to feed their crops. Experience has shown them that all composts are not equal. They prefer buying from a source where the compost recipe is consistent from year to year. They use primarily dairy manure based compost (Dairy Doo[1]) (Figure 10), but have also used poultry manure based compost and composts containing wood ash. The compost is spread using a poultry spreader on 30-foot swaths using a light bar, resulting in a fairly even spread (or a lime spreader) (Figure 19).

They exclusively use dried chicken manure (Figure 9). Drier manure increases the amount of nutrients per ton and makes it easier to spread. The manure is also spread with a poultry spreader.

Both the compost and manure are applied in the fall and incorporated simultaneously using a disk followed by a ripper or a disc chisel with twisted shovels. The application rates of compost and manure vary by the crop to be planted and the previous crop (Table 5).

Figure 19. Poultry (lime) spreader. Gary Powell

These combinations of compost and manure rates are providing adequate nitrogen for the crops and soil. Phosphorus levels are medium to high. They have not noticed any weed shifts or new species due to the compost and manure applied. The only drawback to using compost and manure is the lack of availability close to their operation. Currently the manure needs to be picked up or shipped from across the state.

Table 5. Compost and manure application rates used on Thistledown Farms.

Crop to be planted	Previous crop or cover crop	Compost	Manure
Corn	Clover	1 yd/A	1 – 1-1/2 ton/A
Corn	Beans	None	2 ton/A
Beans	Corn	1 yd/A	None
Wheat	Corn or beans	None	2 ton/A

Weed management sequence (corn and beans)

- Before planting
  - Field cultivator (one to three times)
- Preemergence
  - Tined weeder (once at 8 MPH with the rows)*
- Postemergence
  - Double rotary hoe (once at an average of 7 MPH, occasionally twice)
  - Cultivate (usually 2 to 3 times)
  - Hand weed if necessary

*If there is a lot of corn stubble/trash left over they do not use the tined weeder

[1]Dairy Doo is a product of Morgan Composting, Inc., 4353 U.S. 10, Sears, MI 49679, dairy-doo.com

"Compost isn't compost; you need a reliable source."

Ben Sattelberg

"If manure isn't dry you're paying for water."

Ben Sattelberg

For further reading:

- **Best Management Practices: Manure Management**. 2005. Available from the Ontario Ministry of Agriculture, Food, and Rural Affairs. For ordering on-line go to: http://www.omafra.gov.on.ca/english/environment/bmp/series.htm#Soil or telephone the Ontario Federation of Agriculture at 416-485-3333
- **Weed Seeds and Manure**. by C. Brown and M. Cowbrough, Ministry of Agriculture Food and Rural Affairs accessed 6/2/08 http://www.omfra.gov.on.ca/english/crops/field/new/croptalk/2006/ct-1106a2.htm
- **Weed Seed Survival in Livestock Systems**. 2005. J. Katovich and R. Becker, Univ. of Minnesota and J. Doll, University of Wisconsin. available on line at: http://www.manure.umn.edu/assets/WeedSeedSurvival.pdf

Steps to take to avoid introducing a new weed species to farm fields and increasing weed problems:

- Keep purchased animals confined to an area for up to 5 days and check fields where the manure is then spread for potential new weed species.
- Manage weeds in all grain and forage fields so harvested feeds for livestock are as weed free as possible.
- Spread fresh manure on weedy fields if feeding weedy feedstocks can't be avoided. The weed seeds in the manure will make less of a difference in the weediness of an already weedy field.
- Stockpile manure to reduce the number of viable seeds in the manure.
- Compost the manure for two months if possible. Turn the compost so temperatures in all areas of the pile exceed 130° F for 3 or more days. The top and edges of the pile need to be turned under to destroy weed seeds.
- Low temperature anaerobic digesters do not destroy weed seed as well as high temperatures and or composting so plan accordingly.
- Scout fields and be prepared to manage weeds in a timely fashion.
- Weed growth in manured fields will often be more vigorous because nutrients have been added and soil quality improved. The crop will also benefit from the applied nutrients and improved soil quality.

Chapter 4

Flaming for Weed Management

Author: Erin Taylor

Contributors: Stevan Knezevic and Santiago Ulloa

The idea of using fire to control weeds is not a new one. Kerosene and diesel flamers drawn by horses were used for the first time nearly 100 years ago. In the 1940s and 1950s flaming use increased, using propane, butane, and kerosene as fuels. By the mid-1960s flaming reached its peak with 25,000 flamers being used nationwide. Since that time, flaming has drastically decreased in popularity due to the increased price of liquid propane and the increased efficiency and affordability of herbicides. Today's farmers have little or no experience with flaming for weed control. With the current demand for organically produced goods, flaming is once again a useful tool for weed control. In this chapter we answer some of the questions surrounding the use of propane flamers.

How a flamer works

Running a flame over plants causes the water temperature in plant cells to rise and the cells to expand. Internal plant temperatures need to reach 130 to 200° F to cause

Figure 1a. Pull behind 8-row flamer with 2 burners per row directly over the row. Erin Taylor

Figure 1b. Three point hitch mounted 4-row flamer with 2 burners per row set perpendicular to the row at a ~60 degree angle to the ground. Ron Dunphy

Figure 1c. Three point hitch mounted 6-row flamer with 2 burners per row, set perpendicular to the row at a 45° angle to the ground. Erin Taylor

Figure 1d. Four-row research flamer with 2 burners per row set perpendicular to the row at adjustable angles. Stevan Knezevic

rupturing of the plant cell membranes. The ruptured membranes lead to rapid water loss (dehydration) and eventually death of the plant.

Small annual broadleaf weeds (i.e. < 2 inches) with thin leaves and few, unprotected growing points are the most susceptible to flaming. Weeds that are more tolerant to flaming either have ways of avoiding the heat or the ability to initiate new growth after flaming. Examples of tolerant weed features include larger stature, fleshy and/or hairy leaves, protected growing points, and extensive root systems.

Besides the use of hand labor, flaming and cultivation are two methods for combating weeds within the crop rows. Flaming, unlike cultivation, can be done at times when the soil is too wet for tillage. Tillage and cultivation often trigger weed germination and emergence. Flaming does not disturb the surface of the soil and therefore does not trigger a new flush of weeds. Some of the best results for flaming have been achieved when a soil crust is present; the soil crust acts as a barrier to stop new weed seedlings from emerging.

Figure 4. Backpack flaming organic carrots before emergence at the Michigan State University Student Organic Farm. Erin Taylor

Figure 2. Broadcast flamer with four burner units set 12 inches apart. Stevan Knezevic

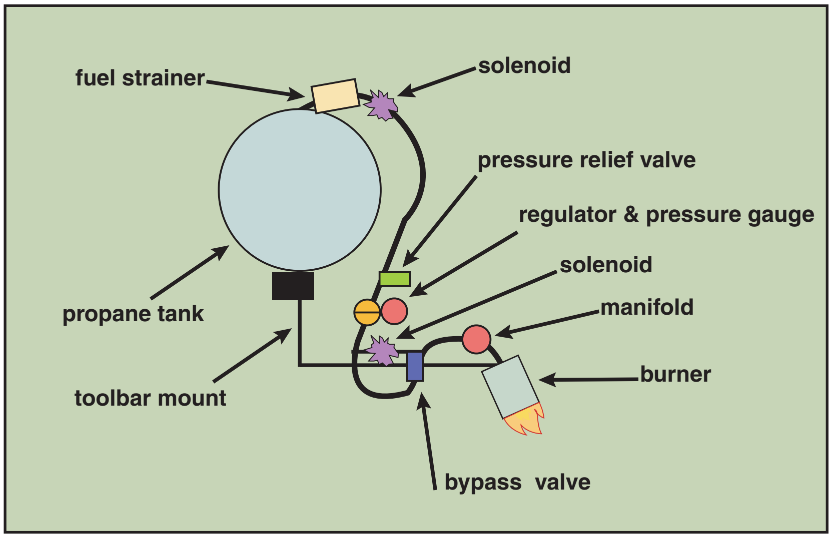


Figure 5. Basic components of a band flamer.

Figure 3. Flaming at the base of corn plants controls weeds within the row. Erin Taylor

Flamer setup

Large scale flamer units can be built on pull behind trailers or toolbars mounted using a three-point hitch (Figure 1). They can be designed to broadcast flame (Figure 2) or band flame over the row or in-between the rows (Figure 3). Smaller units for spot treatments, fence rows, or garden use can be built on carts or carried in a backpack with a long-handled torch (Figure 4).

The basic components of a band flamer are described in Figure 5.

The burners of band flamers can be set perpendicular to the row or angled to aim at the base of crop plants where weeds are hardest to kill. Angles ranging from 22.5 to 60 degrees with respect to the soil surface are ideal. Most band flamers use two staggered burners per row (Figure 6). The burners are staggered to avoid turbulence and crop damage. Fuel use ranges from 5 to 10 GPA depending on pressure and speed (ATTRA 2002, Flame Engineering 2008a).

Accessories

Some burner units can be fitted with shields to direct the heat and/or protect the crop. The use of water while flaming is another way to protect the crop. Research on young cotton (8 to 10 inches tall) indicated that the use of a water spray above the burners reduced upper crop canopy damage by 8 to 19%, depending on the propane pressure (Seifert and Snipes 1998).

Figure 6. Burners need to be staggered to avoid turbulence, which makes flaming less effective. Erin Taylor

Information on flamer parts or purchasing complete flamer setups can be found at:

Flame Engineering, Inc.
P.O. Box 577
LaCrosse, KS 67548
888-388-6724
www.flameengineering.com

Thermal Weed Control Systems, Inc.
N1940 State Hwy 95
Neillsville, WI 54456
715-743-4163

LP Weed Burner
56360 200th Street
Wells, MN 56097
(507) 553-5633

Flame Weeders
Rt. 76, Box 28
Glenville, WV 26351
304-462-5589
www.flameweeders.cjb.net

Conditions for flaming

Crop selection

The crop and its growth stage should be the number one factor in determining whether or not to use a flamer. The growing point of the crop must be protected if the flamer is going to be used to control weeds within the row. Soybeans can be flamed before they emerge or just after emergence when the cotyledons are closed around the growing point (Figure 7). Dry beans should be flamed before they emerge only. As they can be damaged even when the cotyledons are closed. Corn is one of the safest crops to flame because the growing point remains protected below the surface of the soil until the V4 growth stage. However, even corn has been shown to be damaged when the flaming settings or timing is off. In a study by Knake et al. in Illinois in 1965, corn populations and yields were significantly reduced when 2-inch tall corn was flamed twice sequentially; tractor speed was 1 MPH and propane pressure was 28 PSI.

Figure 7. Soybeans need to be flamed pre-emergence (above) or just after emergence when the cotyledons are still closed around the growing point (below). Erin Taylor

Table 1. Flame weeding has been studied for various crops at various growth stages of the crop.

Crop	Stage/height	Injury	Other notes	Source
Apple				Bond and Grundy 2001
Asparagus				ATTRA 2001
Beets	preemergence	none		ATTRA 2002
Cabbage	14 week old transplants	2-60% injury 5 days after flaming, not noticeable 20 days after flaming		Wxzelaki8 at al. 2007, Bond and Grundy 2001
Carrot	preemergence			ATTRA 2002
Cole crops	2-3 weeks after transplanting			ATTRA 2002
Coriander				Bond and Grundy 2001
Corn	up to V6	some leaf damage which is usually outgrown		(unpublished)
Corn	2-20 inches	no effect on corn population or yield at 4 MPH, 20 PSI		Knake et al. 1965
Cotton	8-10 inches height	11% injury for 15 PSI, 24% injury for 175kPa		Seifert and Snipes 1998
Cotton	16-18 inches height	4% injury for 15 PSI, 7% injury for 175kPA		Seifert and Snipes 1998
Cotton	8-10 days after emergence	no comment	yielded slightly higher than cultivated plants	OFRF 1999
Cotton	16-21 days after emergence	no comment	yielded slightly higher than cultivated plants	OFRF 1999
Dill				Bond and Grundy 2001
Onion	2-3 inches height			ATTRA, Bond and Grundy 2001
Onion	1.5-2.3 inches height	no comment		Mojzis 2002, Virbickaite et al. 2006
Onion	8-10 inches height	no comment		Mojzis 2002
Onion	16-20 inches height	no comment		Mojzis 2002
Parsley				Bond and Grundy 2001
Parsnip	preemergence	none		ATTRA 2002
Popcorn	8-10 days after emergence	no comment	yielded slightly higher than cultivated plants	OFRF 1999
Popcorn	16-21 days after emergence	no comment	yielded slightly higher than cultivated plants	OFRF 1999
Potato				deWild
Soybean	preemergence	none		(unpublished)
Soybean	hook stage, with closed cotyledons	some blistering of cotyledons quickly outgrown		(unpublished)
Soybean	8-10 and 16-21 days after emergence	no comment	yielded slightly higher than cultivated plants	OFRF 1999
Spinach	preplant	none		Boyd et al. 2006
Sweet corn	4 inches to canopy	no comment		ATTRA
Tomato	10 week old transplants	2-30% injury 5 days after flaming, not noticeable 20 days after flaming		Wszelaki et al. 2007
Tomato	8 week old			ATTRA 2002

*preemergence: before the crop has emerged

Flaming for weed control has been studied on several different crops, which are listed in Table 1 with their corresponding stage/size at flaming and any resulting crop injury that was observed.

Weeds and growth stages

While flaming any weed will result in some degree of damage, catching weeds when they have just emerged and are quite small is the key to control. Small (i.e. 1-4 leaves) common lambsquarters and chickweed were two of the most sensitive weeds to flaming, requiring only 5 gallons LP/A (GPA) (18 lbs. per acre) for 95% control (Ascard 1995) (Table 2). In contrast, pineapple-weed required 21 GPA (77 lb. per acre), and annual bluegrass was not killed with a single flaming at any rate! Larger weeds (4 to 12+ leaves) required doses between 5 to 39 GPA (18 to 162 lbs. per acre) to achieve 95% control.

Table 2. Sensitivity of weeds to flaming.

Sensitive to flaming	Moderate	Tolerant to flaming
common lambsquarters	common purslane	annual bluegrass
common chickweed	ladysthumb	foxtail species
pigweed species	common groundsel	crabgrasses
velvetleaf		common ragweed
		pineapple-weed
		mustards

Sources: Ascard 1995, on-farm trials (i.e. unpublished data), Gene Vogel.

Figure 8. Common lambsquarters before (left) and after (right) flaming. 📷 **Erin Taylor**

After flaming plants are not charred. Although very small weeds will appear to disappear after flaming (Figure 8), larger plants may look the same as before flaming with only slight changes in color or singeing around the edges. Plants will look progressively worse as they dehydrate and die.

A quick test

While calibrating a flamer it is useful to conduct a simple fingerprint test to see if flaming is effectively killing plant tissue. Immediately after flaming, firmly press a leaf between your thumb and index finger. If a darkened impression remains, it is likely that the tissue will dehydrate and die within a few hours or days (Figure 9).

Figure 9. The fingerprint test serves as an early indicator of flaming success. 📷 **Erin Taylor**

Flaming only controls the weeds that you can see. If weeds continue to emerge in the field, a second pass with the flamer or a cultivator may be required. A second pass may also be required for perennials, grassy weeds, and annual broadleaf weeds greater than 2 inches in height. Always check the crop! If the crop has grown out of the "safe" stage for flaming, cultivation or hand labor are two weed control options.

Settings

Plant tissue may need to reach up to 200° F to be killed. The temperature of the flame can be regulated by changing the pressure of the flamer, the speed, the orientation of the burners, or the distance of the burners from the target weed.

These results (Figure 11) suggest that there is no one speed (and therefore dose) that will work consistently from year to year. Calibration using the fingerprint test is important every year in every field.

Figure 10. Though large crabgrass (left) is damaged by flaming (right) it may grow back from its protected growing point. 📷 Erin Taylor.

Speed

Adjusting tractor speed can be used to change flame temperature, duration of exposure, and use rate per acre (when combined with pressure). Slower speeds increase the amount of heat that weeds are exposed to but it is also more costly because more propane is used per acre. The National Sustainable Agriculture Information Service (ATTRA 2002) recommends speeds ranging from 3 to 5 MPH for weed control in vegetables. In 2007 Wszelaki et al. did a two-year speed trial in tomato and cabbage. The best flaming speed for controlling broadleaf weeds and producing good yields in transplanted tomato was 2.5 MPH. Cabbage growth was slowed by flaming and harvest postponed by two weeks in one year of the two year study. Weed control results also varied from one year to the next. In the dry year, weed control from flaming lasted longer.

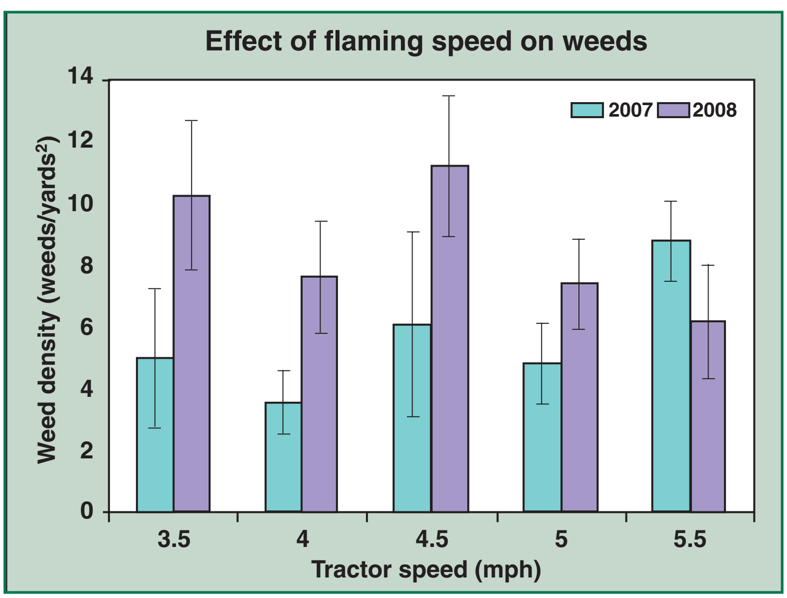


Figure 11. 2007 and 2008 weed densities 4 to 6 days after flaming.

In a two-year study in Michigan, we compared tractor speeds of 3.5, 4.0, 4.5, 5.0, and 5.5 MPH. Pressure was constant at 35 PSI in 2007 and 40 PSI in 2008. Common lambsquarters, common ragweed, and giant foxtail were in the cotyledon stage at the time of flaming and less than 1 inch in height. Damage to the weeds was immediately apparent after flaming both years (Figures 9 and 10). There were more weeds in 2008, but slower speeds did not improve weed control in either year. These results (Figure 11) suggest that there is no one speed (and therefore dose) that will work consistently from year to year. Calibration using the fingerprint test is important every year in every field.

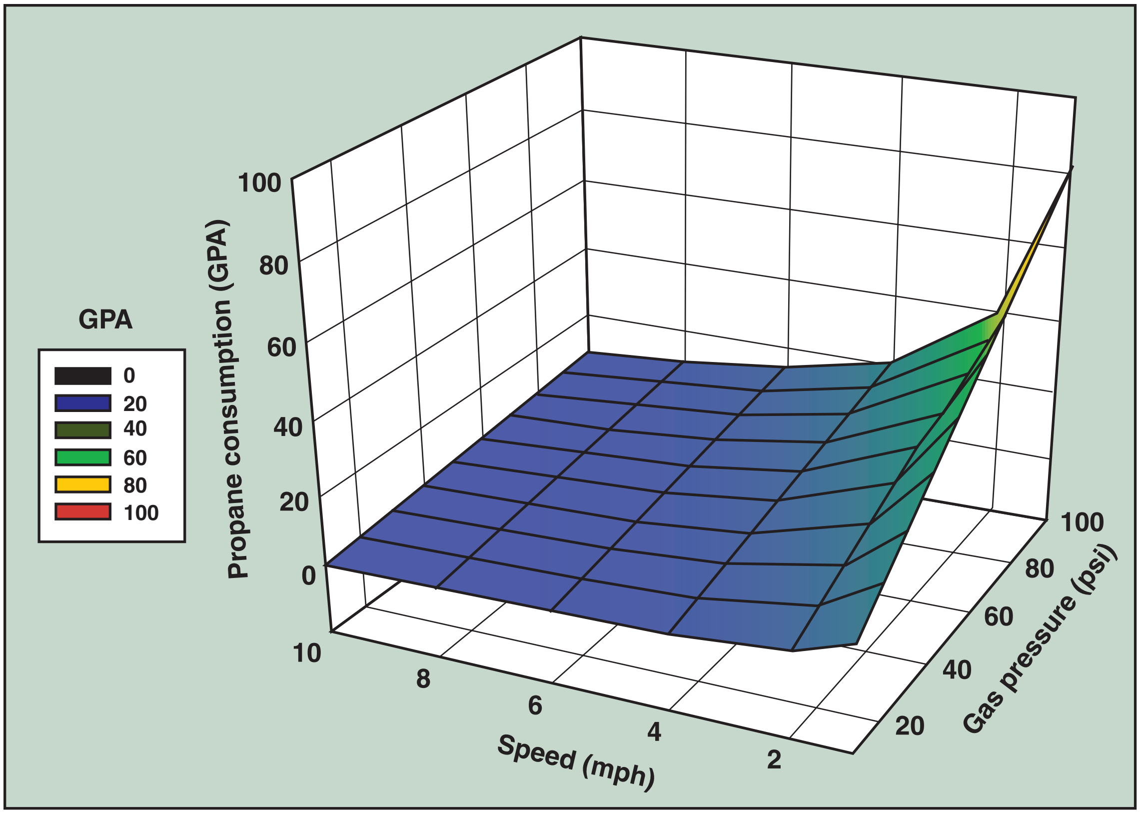
Pressure

Pressur, in combination with speed, is important because it determines the actual use rate of propane per acre. Pressures tested in studies have ranged from 10 to 90 PSI. In 2002, Mojzis studied the effect of combinations of speed (1.2-3.1 MPH) and pressure (21 to 36 PSI) on weed control in onion at various heights. The slowest speed and highest pressure killed the most weeds, but it also did the most damage to onion.

Propane consumption

Looking at propane consumption in GPA is one way to derive a dose from combinations of pressure, speed, and burner spacing. Recently, Knezevic and Ulloa (2007) and Heverton et al (2008), examined the use rate of propane per acre. They studied the response of crops and weeds to broadcast flaming. The flamer consisted of four burners (LT 2x8) (Flame Engineering 2007) mounted on a

Figure 12. Broadcast flamer with four LT 2x8 burners. 📷 Steven Knezevic



Pressure (PSI)	Speed (mph)					
	1	2	4	6	8	10
10	10.24	5.12	2.56	1.71	1.28	1.2
20	18.16	9.08	4.54	3.03	2.27	1.82
30	26.08	13.04	6.52	4.35	3.26	2.61
40	34.00	17.00	8.50	5.67	4.25	3.40
50	41.92	20.96	10.48	6.99	5.24	4.19
60	49.84	24.92	12.46	8.31	6.23	4.98
70	57.76	28.88	14.44	9.63	7.22	5.78
80	65.68	32.84	16.42	10.95	8.21	6.57
90	73.60	36.80	18.4	12.27	9.20	7.36

Figure 13. Propane consumption chart for broadcast flaming with Flame Engineering's LT 2x8 with burners mounted 12 inches apart (Flame Engineering, 2008b).

square bar set 12 inches apart, 8 inches above soil surface, and angled at 30 degrees to the soil (Figure 12). Flaming treatments were applied using a constant speed of 4 MPH (Knezevic et al. 2007). Propane pressures included: 0, 10, 30, 50, 70 and 90 PSI, which given these settings corresponded to propane consumption rates of: 0, 3, 7, 10, 14 and 18 GPA, respectively (Figure 13). The species evaluated included: corn, sorghum, soybean, sunflower, barnyardgrass, green foxtail, velvetleaf and redroot pigweed.

Figure 14. Dead velvetleaf 14 days after broadcast flaming. Stevan Knezevic

Figure 15. Damaged grass growing back after flaming. Erin Taylor

In general, the plant response to flame varied depending on the species, growth stage and propane rate. Broadleaf weeds were much more susceptible than grasses (Figures 14 and 15). About 90% control of broadleaf weeds was achieved with up to 10 GPA. Grasses were more tolerant, requiring propane rates of up to 25 GPA.

Burner angle and height

The hottest part of a flame is at the tip of the inner blue cone (Figure 16). Varying the angle of banded burners and the height changes where the most intense heat strikes the target weeds.

Figure 16. The tip of the inner blue cone is the hottest part of a flame. Erin Taylor

Figure 17. Safety precautions are a top concern with flaming. Erin Taylor

Figure 18. Cautiously light pilot lights. Erin Taylor

When targeting weeds at the base of crop, researchers recommend a range of burner angles from 22.5 to 60 degrees from the ground and heights 2 to 12 inches above the ground/base of the crop. Make adjustments in the evening when the flame is more visible.

Safety hazards and precautions

- Tractors with cabs protect the driver in the event of an accident.
- Lighting the pilot lights for the burners should be done cautiously with a long handled torch (Figure 18).
- Fence rows, excess corn stubble, and other residues are fire hazards.

"We aren't concerned enough about safety." Gene Vogel

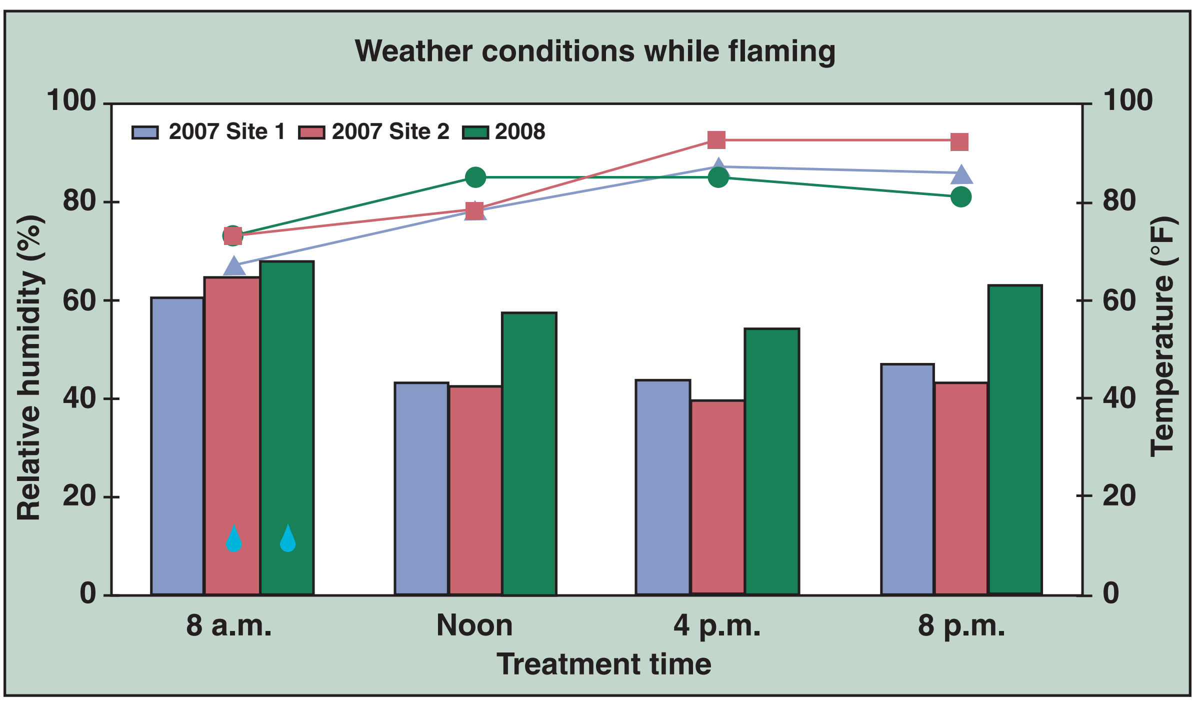


Figure 19. Relative humidity (rectangular bar histogram) and temperature (line graph with points) throughout the day at each of the sites. = dew present.

- ▲ Mid to high wind speeds decrease the effectiveness of flaming and can cause heat to build up on tractor tires.
- ▲ Pressure relief valves are more likely to blow when the tank is less than 50% full and when air temperatures are high.
- ▲ Check old hoses for leaks regularly.

Weather conditions

The presence of dew reduces the intensity of heat reaching the surface of the weeds during flaming. This, in turn, can reduce the level of weed control. We measured the effectiveness of band flaming in corn at four different times throughout the day: 8 a.m., noon, 4 p.m. or 8 p.m. The six-row flamer was targeted directly at the base of the corn rows, at an angle of 45 degrees to the ground. Burners were run at 30 PSI, and the tractor traveled 4 MPH. The relative humidity and temperature at each time of day are shown in Figure 19. There was dew present at the 8 a.m. flaming time at site 2 in 2007 and in 2008.

Broadleaves ranged from 1/8 to 1 1/2 inches in height at the time of flaming. Flaming reduced the number of in-row broadleaf weeds by 44 to 96% (Figure 20). In 2007 the 8 p.m. treatment was the least effective in controlling broadleaf weeds. Common ragweed, clover, and common purslane were harder to control than pigweed, velvetleaf and common lambsquarters. In these two years, the presence of dew did not reduce flamings effectiveness on weed control.

Grassy weeds including giant foxtail and large crabgrass were not controlled by flaming at any timing. Interestingly, there was an increase in the number of grassy weeds four days after flaming compared with the original counts prior to flaming. Other studies have also shown an increase in weed density after flaming. Several factors may account for this phenomenon, such as increased germination (or reduced dormancy) due to exposure to high temperatures or increased sunlight reaching the soil surface after other weeds are killed (Ascard 1995).

Overall, differences in flaming effectiveness were not explained by humidity and temperature since the greatest changes in relative humidity and temperature did not produce distinguishable differences in weed control. However, broadleaf weed control was consistently above 80% for the noon flaming time.

Common ragweed, clover and common purslane were harder to control than pigweed, velvetleaf and common lambsquarters.

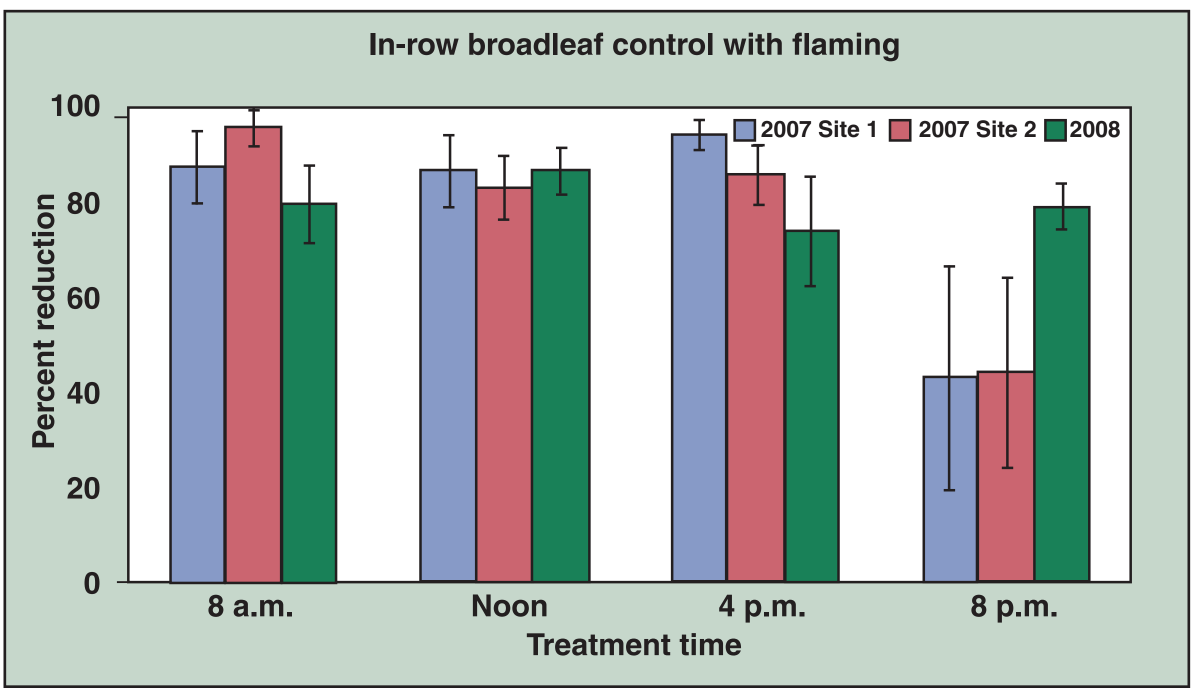


Figure 20. Reduction in broadleaf weed density 5 to 6 days after flaming.

Economics

Flaming may or may not be economical for your operation. The economics will depend on the value of the crop and other inputs to the system. For example, in a two year study in Michigan, we compared the effectiveness and economics of controlling in-row weeds in soybean using a propane flamer (F) (i.e. 4 MPH, 35 PSI), a rotary hoe, and a combination of the two. There was no difference in broadleaf weed control among the three weed control treatments in 2006 (Table 3). Giant foxtail was more prevalent where we only rotary hoed (Figure 21); hand weeding these plots took longer. The flaming only treatment was the least expensive ($46 per acre) in this year. In 2007, there were no differences in weed populations, probably due to low overall weed pressure. The rotary hoeing only treatment was the least expensive ($35 per acre). Over the two years the most consistent treatment for costs and weed control was the rotary hoe + flaming treatment.

Figure 21. In 2006, rotary hoe only plots (left) had higher giant foxtail densities than flamed plots (right). Erin Taylor

Additional benefits of flaming

Several studies have been conducted to examine other potential benefits of flaming such as control of insects and diseases.

Insects

Colorado Potato Beetle (CPB) – There was 90% control of CPB when it was warm and sunny and the beetles were feeding (ATTRA 2003). Flaming reduced egg hatch by 30%. Colorado potato beetle mortality was highest when flamed at the L1-2 life stage (Rifai et al. 2004/5). Older CPB were found to be more heat tolerant.

Tarnished plant bug – In a study on the cotton pest tarnished plant bug and the beneficial convergent lady beetle both insects on the soil surface were killed by flaming. However, 8 inches above the ground in the cotton canopy the lady beetles were less affected by flaming than the tarnished plant bug (at 25 PSI) (Seifert and Snipes 1996).

Other insect species reduced by flaming include the alfalfa weevil (Flame Engineering 2008a) and young boll weevils in cotton (Seifert and Snipes 1996).

Table 3. Economic data (i.e. fuel and hand labor only) from 2006 and 2007.

	2006						2007					
	Rotary hoe		Flamer		Rotary hoe + flamer		Rotary hoe		Flamer		Rotary hoe + flamer	
	passes	cost	passes	cost	passes	cost	passes	cost	passes	cost	passes	cost
Rotary hoe	5	$2.45	1	$0.49	5	$2.45	3	$1.23	–	–	3	$1.23
Flame	–	–	1	$9.35	–	–	–	–	1	$13.59	–	–
Cultivate	4	$3.86	4	$3.86	4	$3.86	4	$3.20	4	$3.20	4	$3.20
Hand weed*	1	$48.14	1	$32.09	1	$32.09	1	$30.50	1	$36.77	1	$24.40
TOTAL		$54.45		$45.79		$47.75		$34.93		$53.56		$42.42

*Hand weeding price is influenced by the amount of time required to remove weeds.
† In 2006, the flaming treatment ended up being rotary hoed one time to promote soybean emergence.
‡ In 2006 propane was price at $1.29 per gallon, diesel was $2.12 per gallon. In 2007, propane was $1.55 per gallon and diesel was $2.29 per gallon.

Diseases

Tomatoes flamed for weed control had a decreased incidence of blossom end rot (Wszelaki et al. 2007). Potatoes flamed before harvest prevented the onset of late potato blight in the tuber. Flaming mint residues reduced the amount of *Verticillium* and rust inoculum returned to the soil.

Flaming references

- Sustainable Agriculture Network: **Steel in the Field: A Farmer's Guide to Weed Management Tools** 2001. Sustainable Agriculture Network, Edited by Greg Bowman. Available at: http://www.sare.org/publications/steel/steel.pdf
- MSUE bulletin E-3038: **Flaming as a method of weed control in organic farming systems** 2007. Michigan State University Extension, D. Mutch, S. Thalmann, T. Martin, and D. Baas.

Farmer profile

Gene Vogel, Minden City, MI

Gene Vogel farms 700 acres in Minden City, Michigan. He started farming organically in 1995 and by 1999 all of his fields were organically certified. Mr. Vogel controls weeds using a propane flamer and a variety of tillage and cultivation implements.

Rotation

Year	Season	Crop/Cover crop
Y1	Winter	Clover stubble
	Spring	Corn
	Summer	
	Fall	Rye
Y2	Winter	
	Spring	Beans [soybeans, dry beans (pinto or black), snap beans]
	Summer	
	Fall	Small grain (wheat or spelt)
Y3	Winter	
	Spring	Clover (medium red)
	Summer	
	Fall	

= harvest = incorporated

Nutrients

One ton per acre of dry poultry (layer) manure is applied and worked in the fall before corn and wheat/spelt.

Weed management operations (corn and soybeans)*

Flame once

Double rotary hoe once

Cultivate three times

* varies based on the weather each year

Flaming

Mr. Vogel started flaming with a borrowed unit in 1995. He then went on to build his own unit. After experimenting with the number of burners per row and the angle, he now prefers his 12-row flamer with one burner unit per row; running perpendicular to the row (Figure 22). He intends to build a second flamer with angled burners for use in corn with foxtail infestations

Figure 22. Three point hitch mounted 12-row flamer with one burner aimed directly over the row (lower left) built by Gene Vogel. Erin Taylor

Settings

Speed = 5 mph

Pressure = 30 psi, unless there are several hard to kill weeds (e.g. common ragweed, foxtails, mustards)

Burners height = 8 inches above ground

Fuel consumption = 3.5 to 4 gallons of propane per acre

Conditions

Best results mid-day with sun shining and ideally low wind speeds

Avoid dew

Crop stage

Soybeans – cotyledon stage

Dry beans and snap beans – preemergence (before the crop emerges)

Corn – spike to 4 to 5 leaves, 2 to 3 leaves ideally

Weed stage

In the beans – weeds have ~2 leaves

In the corn – weeds can be slightly larger because the corn is more tolerant to flaming

Tips

Be concerned about safety

Look for blue tip of the flame, you want that touching the ground

Do not let flames bump into each other

Improvements still to come

Wider flame with single burner

Shields that increase efficiency

Spark-lighting pilot lights that can be lit from inside the tractor

Monitor for burners in the tractor

Farmer's comments

"Common ragweed is tough to kill. It looks like it's going to die after flaming, then it grows back from the center." (Figure 23)

Figure 24. After flaming corn looks damaged compared to untreated corn, but later in the season there is no difference. Erin Taylor

"We'll have a burner go out once in a while and the corn will be taller in that row, especially when the corn is small early in the growing season. Later in the season we can't tell where the burner went out, except that row is weedier than the others. You can't see a height difference [in the corn]. When the corn is 8 inches tall it looks like we've hurt it with the flamer, but now, when it's tasseling, it looks like it caught back up." (Figure 24)

Figure 23. Though common ragweed (left) has singed cotyledons after flaming (right) it often grows back from the center. Erin Taylor

Notes

Chapter 5

Grazing and Other Biological Weed Controls

Author: Erin Taylor   Contributor: Rich Leep

Biological control of weeds is occurring every day on every farm. Weed seeds, seedlings and mature weed populations are reduced each day by animals, insects and soil microorganisms.

In "Integrated Weed Management 'One Year's Seeding…'" the three methods of biological control (see right) were discussed on pages 65 – 70, and detailed information was presented on seed predation. In this chapter we focus on managing weed seedlings and larger weeds in the vegetative and reproductive stages of growth.

Vegetative and reproductive weeds can be predated by vertebrate animals, such as livestock, herbivorous insects, fungi and other microorganisms.

Methods of biological control

Conservation

Populations of control agents that already exist in a field are maintained or increased by providing good habitat. Example: no-till fields provide cover for field mice that predate weed seeds.

Inoculation

Small numbers of an organism foreign to the field are applied and allowed to spread through the field; may be long-lasting.

Inundation

Large numbers of an organism foreign to the field are applied to spot-treat the weed problem; short-lived effect.

Adapted from "Integrated Weed Management: 'One Year's Seeding…'" (E-2931).

Vertebrate animals

Grazing livestock is perhaps the most practical biological control option for farm operations. Livestock can graze pastures, rangeland, orchards, and crop fields before planting or after harvest (Figure 1). Many weeds, such as dandelion and quackgrass, are actually nutritious for livestock to consume. However, some weeds can be noxious or compete with more desirable plant species in the pasture. The effectiveness of grazing varies by weed susceptibility, grazing animal, and site.

Weed susceptibility

There are several physical and chemical characteristics that can make a weed more or less likely to survive grazing (Table 1).

Figure 1. Heifer grazing at the MSU Beef Cattle Research and Teaching Center. Erin Taylor

"I think healthy soil with lots of living organisms destroys many weed seeds." – Dennis Kellogg

Grazing is useful for three means of weed control:
1. Reduce total biomass
2. Reduce the biomass of a single species or group
3. Reduce weed seed production and survival.
Adapted from Liebman 2001

Table 1. Characteristics of weeds that influence susceptibility to grazing pressure (Figure 2).

Less likely to survive	More likely to survive
Upright growth	Prostrate growth
Growing points up off the ground	Growing point near or below soil surface
Few growing points	Several growing points
Limited flowering time	Continuous flowering
Few flowers, rhizomes or stolons	Many flower, rhizomes or stolons
Palatable to grazer	Presence of spines or thorns
High nutritional value	Low nutritional value
	High in secondary metabolites
	Seed can survive digestion





Figure 2. (Clockwise from upper left) Pigweed, smartweed, and giant ragweed are all examples of weeds that are susceptible to grazing, while common cocklebur and bull thistle are less likely to be grazed. Erin Taylor

The life cycle and conditions in which the weed is growing can also play a role in successful grazing. Seedlings are often more susceptible to grazing than established plants because they do not yet have plant defenses, root/carbohydrate reserves, or multiple growing points. Canada thistle is an example of a weed that is successfully grazed by sheep and cattle when it is a seedling because it does not yet have spines or an established root system (Figure 3). Older Canada thistle, especially plants that are flowering, can be grazed by goats, but extensive root systems and the presence of underground buds greatly increase the chance of regrowth.

Figure 3. Canada thistle seedlings (above) and mature plants are grazed differently depending on animal type.
Erin Taylor

Grazing animals

Preferences and tolerance to grazing varies by plant species and animal species. Following are a few examples of weeds that are eaten by livestock, along with weeds known to poison the animals.

Erin Taylor

Sheep

Palatable: Leafy spurge, buttercups (*Ranunculus* spp.), tansy ragwort (*Senecio jacobea*), larkspur, spotted knapweed, giant hogweed

Poisonous: bitterweed, rabbit bush

Erin Taylor

Cattle

Palatable: Bracken (*Pteridum* spp.), giant hogweed, dandelion, quackgrass

Poisonous: sacahuista, larkspur, seedling cocklebur, horsetail, bracken fern

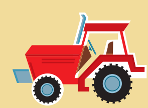
D.W. Rozeboom

Swine

Palatable: Purple nutsedge, volunteer potato

Poisonous: cocklebur

"Keeping healthy field boundaries improves biological control of weeds and insects." – Douglas Custer



"I feel wild turkeys, pheasants, crows, geese, black birds, ground sparrows, etc. consume a lot of weed seed." -Anonymous

Goats

Palatable: Thistles, brush weeds, poison ivy, poison oak, poison sumac, blackberry, sweet briar, gorse, leafy spurge, ironweed, giant ragweed

Poisonous: Oaks (*Quercus* spp.)

Steve Deming

Horses

Poisonous: field horsetail, bracken fern, buttercup, clover, chokecherry, common cocklebur, corn cockle, fescue, foxglove, foxtail, hoary alyssum, mustard, sweetclover, bittersweet, white snakeroot, larkspur

Erin Taylor

Poultry/Fowl

Palatable: Purple nutsedge

Poisonous: corn cockle

Erin Taylor

Other weeds poisonous to many animals

Lupines, swamp camas, milkweed, cornflower, nightshades, sneeze-weed, dogbane, bane-berry, laurels, wild cherry, choke cherry, pin cherry, horsenettle, Indian tobacco (*Lobelia inflate*), cocklebur, horsetails, water hemlock, sneezeweeds, corn cockle seed, St. Johnswort, poison hemlock, jimsonweed, pokeweed, death camas, locoweed, aslike clover, buttercup, bracken fern, dogbanes, poison hemlock, pigweed, bouncing bet, young or damaged shoots of johnsongrass, Ohio buckeye, wild indigo, wooly croton.

"We feed the birds and have a lot of Goldfinches. When the thistles go to seed in the cow lot, the finches clean them up." – Anonymous

"A system with a planned phase of planted pasture intensively rotational grazed can provide a boost to weed control, excellent soil conditioning and a revenue source." – John Simmons

In some cases livestock can be trained to graze weeds they normally would not. Walker et al. (1992) exposed newborn sheep to leafy spurge through water soluble extracts (mixed with milk replacer) and as fresh plants for 11 weeks. This increased the sheep's preference for leafy spurge. In a penned feeding trial, heifers who were fed snakeweed and then rewarded with a starch supplement consumed more snakeweed than heifers receiving no starch (Ralphs and Weidemeir 2004). Once the cattle were put to pasture and supplementation ceased there was no difference between the conditioned animals and the non-conditioned animals. Increasing stocking rate (i.e. decreasing paddock size) increased acceptance of snakeweed by both groups.

Grazing system

High density grazing (aka mob-grazing) will work well if you are trying to control many different weed species as many animals placed into a paddock for a short period of time will graze existing vegetation more uniformly. Set-stocking, which involves placing a set number animals into a larger pasture, gives the animals more feed to choose from, resulting in selective grazing which often times increases populations of undesirable weed species. Sometimes, one can implement a leader-follower grazing system where the high producing animals are given an area first for prime grazing followed by lower producing animals grazing what vegetation remains. This will usually achieve results similar to mob-grazing.

Keys to successful weed control by grazing

- *Use mob or leader-follower grazing systems to graze more uniformly*
- *Use a variety of animal types*
- *Move fences to keep animals in/out of specific areas and to target specific weed growth stages*
- *Increase stocking rates when weed targets are less palatable*
- *Provide a water source in each paddock to allow animals to graze more uniformly*
- *Do not over graze; leave at least 4 inches of residue for regrowth of pastures*
- *Combine grazing with other management strategies in areas with significant problems*
- *Have a water source nearby (< 1,000 feet)*

Figure 4. Beef cattle and watering station in pasture. Tim Boring

Grazing site

Weed control by grazing can be affected by the physical characteristics of the site. Cattle prefer sites that are within 1,000 feet of a water source and not on a steep slope (Figure 4). If a weed problem occurs in a less favorable site, smaller paddocks may be needed to concentrate grazing.

Grazing problems

Sometimes grazing stimulates vegetative and/or reproductive weed growth or creates gaps that permit the establishment of new weed seedlings. In a 4-year pasture study, shepherd's purse and dandelion densities increased over time in highly grazed perennial systems (i.e. overgrazing exposed the soil surface and provided a niche for new weeds to emerge) (Harker et al. 2000). An increase in bull thistle populations has also been seen in grasslands grazed by sheep (Figure 5).

Figure 5. Bull thistle's spines deter grazing. Erin Taylor

Good grazing management means leaving adequate residue (4-inch height) and grazing pastures only when in a vegetative stage (8- to 10-inch height). Good grazing practices prevent weed infestations. When over grazing occurs, the existing vegetation will take longer to recover and this will allow more weeds to encroach into the pasture. In some instances, grazing of certain plants may decrease meat quality. For example, in Queensland, Australia grazing parthenium weed less than 14 days before slaughter tainted the meat of sheep (Tudor et al. 1982).

"I find that protecting natural habitat does promote beneficial insects and vertebrates that will help in controlling weed seeds." – Amos Adams

In another study, finishing pigs were allowed to graze on volunteer potato. This decreased the protein content of their diet, resulting in greater fat content of the carcasses and reduced value (Hospers-Brands et al. 2006).

"Late season use of feeder lambs in corn fields control some common lambsquarters and other weeds escaping cultivation." – Anonymous

Insects and plant pathogens

Insects and pathogens (diseases and fungi) that attack weeds are also possible candidates for biological weed control. In the case of insects, those that feed on or lay their eggs in plant tissue can reduce seed and seedling viability of certain weed species. The key to using these agents for biological control is finding the perfect match between weed and control agent. Ideally the insect or pathogen should interact only with the specific target weed to reduce the risk of injuring desirable plants.

Insect and pathogen control agent successes

Using two species of European beetles to control Klamath weed (aka St. Johnswort) in the western U.S. is one of the earliest examples of biological weed control in the U.S. This weed is toxic to cattle and sheep and has invaded millions of acres of rangeland. In the mid-1940s two beetle species were released and within ten years the beetles brought Klamath weed populations down to levels that were no longer problematic (Delfosse 1995).

Alligatorweed, an invasive plant responsible for blocking waterways in several states from the Gulf of Mexico up into Tennessee, was successfully controlled by the release of the Alligatorweed flea beetle, Alligatorweed thrips, and the Alligatorweed stem borer during the 1960s and 1970s. These plant feeding insects were brought to the U.S. from South America where the plant is a native species. These control measures were successful due to the insects' ability to sustain populations in the southern U.S. and their narrow host range (Buckingham 2002).

Puccinia chondrillina is a rust fungus that was introduced to the U.S. in 1975 to control skeletonweed (*Cercosporella juncea*) in the West. This rust reduces weed height, flowers and seeds (Te Beest et al. 1992). When this fungus is used in combination with two insect biological control agents, skeletonweed is controlled.

Insect and pathogen control agent failures

The flowerhead weevil (*Rhinocyllus conicus*) was released in Canada in 1968 and the U.S. in 1969 to control musk thistle and other invasive Eurasian thistles (*Carduus* sp.). Flowerhead weevil adults lay eggs on thistle flower buds. The larvae then feed on the reproductive structures of the plant and reduce seed production. In addition to feeding on *Carduus* sp., the weevil also was found to feed on native thistle genera (i.e. *Circium, Silybum* and *Onopordum*). In a four-year study from 1992 to 1996, infestation of native thistle flowerheads by the weevil increased. This is an example of an insect released for biological control having too broad a host range (Louda et al. 1997).

Sometimes constraints outside of the control agent-weed relationship limit success. For example, in the 1990s the rust-based (*Puccinia canaliculata*) bioherbicide "Dr. Biosedge" was developed to control yellow nutsedge, however large scale production problems have occurred with producing and collecting the spores, so this bioherbicide has not been successful (Mortensen 1998).

The needs of our predators

As most of us know, nothing in life is truly free. There are some things we can do to increase and encourage the predation of weeds by birds, rodents, insects and pathogens.

Methods for attracting and increasing weed predators and parasitoids

- **Reduce tillage**

  Ground beetles known to eat weed seeds are more abundant in no-till or reduced tillage systems. In organic systems it may be difficult to eliminate tillage. However, reducing tillage for a few weeks in the early fall when beetles are the most active can help increase predation.

- **Reduce synthetic and natural insecticide use**

  Both synthetic and naturally produced broadspectrum (i.e. non-selective) insecticides kill beneficial insects as well as detrimental ones. Reducing reliance on these products will increase insect predator populations.

- **Increase and diversify buffer/refuge strips**

  Predators need the same things we need to survive: shelter, food, water and moderate temperatures. Therefore, sustaining populations of predators requires providing shelter and food throughout the year and a climate favorable for growth (e.g. too hot in ag fields). Diverse buffer strips can facilitate these needs. Plants that could be included in buffer strips include:

  - Trees and shrubs: provide nesting sites and over wintering sites
  - Grasses: provide structure to the vegetative portion of buffers
  - Legumes: encourage soil health
  - Native flowering plants: provide nectar and pollen (Figure 6)

- **Consider irrigation timing**

  Irrigating fields when predators are most active will discourage predation. Insect and animal activity is highest when it is cool and/or dark outside.

Figure 6. Adding native flowering plants to buffers and fencerows will provide nectar and pollen to weed predators throughout the growing season. Anna Fiedler

There are only a few known cases where an insect biological control agent has persisted to attack a non-target plant species. However, this number could be greater because of a lack of post-release monitoring. (Blossey 2007)

In some cases a release of a biological control agent that could affect other plant species is still allowed because the costs associated with the spread of the target plant are greater than the risk. (Blossey 2007)

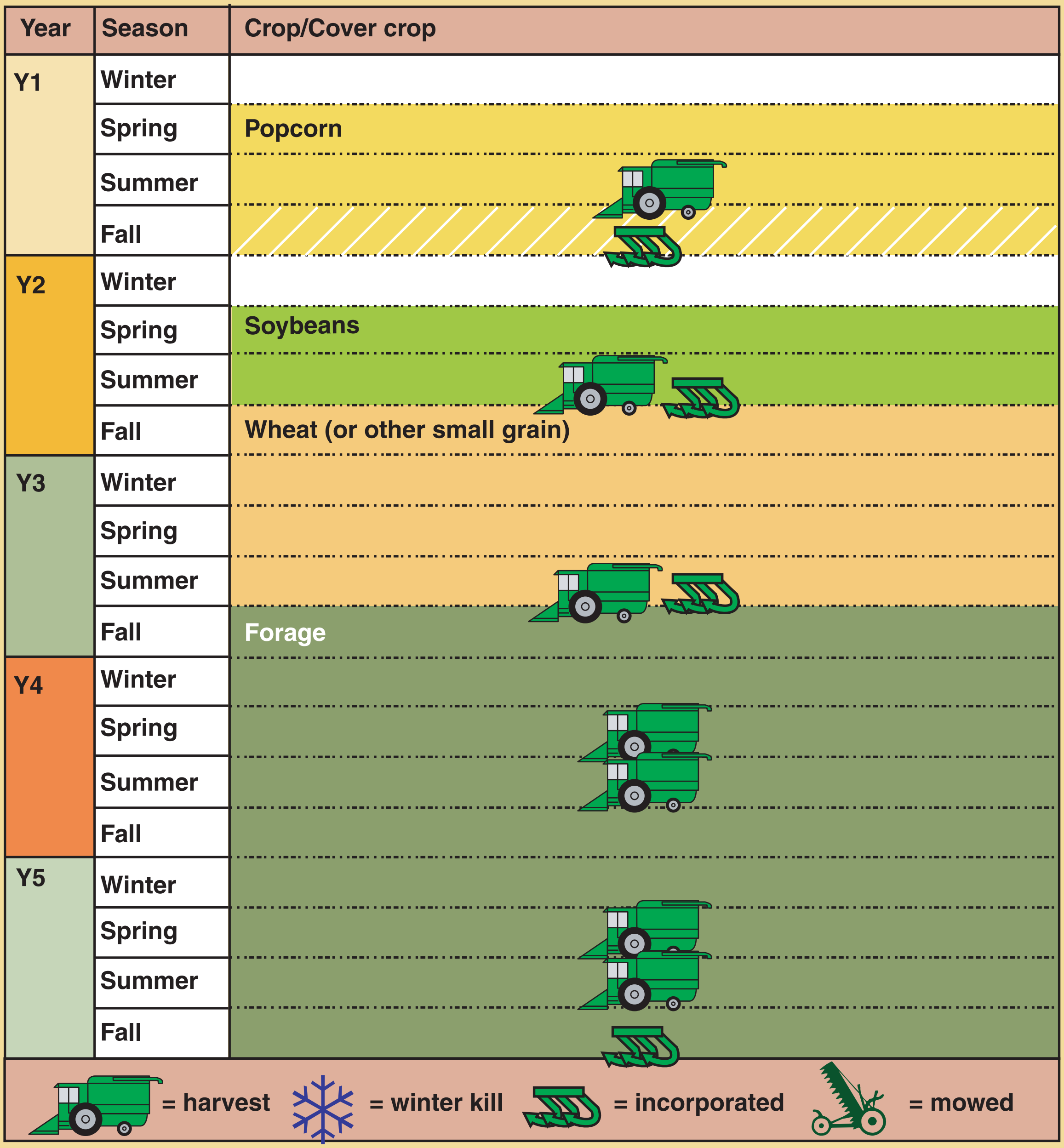
Farmer profile

Gary Reding

Langeland Farms, Inc. (Greensburg, IN)

Gary Reding and his family farm 433 acres in Greensburg, IN in addition to operating a successful seed business. On the farm they grow field crops and raise beef cattle and goats. Portions of the farm and seed business have been organic since 2003.

Rotation



"That forage crop is the key to your rotation for weed control in my book." – Gary Reding

"Two years of grass/forages and you'll have no giant ragweed." – Gary Reding

Nutrients

- Composted chicken litter
  - Applied with a spinner spreader at 2 to 3 tons per acre
  - Only have used for one year, prefers layer litter because of the calcium
  - Put manure on and plow in the fall for popcorn the following spring. This helps biodegrade remaining materials from the forage crop
  - Occasionally if manure is not applied in the fall it is applied and plowed in the spring
- Cattle manure
  - Direct deposit during strip grazing
  - No new weed problems because the manure is from their farm
- Foliar feed products
  - Only the first year of use

Weed management tactics

- Rotation with forages
  - Forages in the rotation break up weed cycles, preventing a build up in the seed bank
  - Stale seedbed preparation
  - Allow early flush(es) of weeds to ger minate, then cultivate again prior to planting
- Mechanical control
  - Rotary hoe (8 MPH)
  - Lilliston cultivator
  - Hand weed
- Animals on the farm
  - Grazing after fields are harvested helps reduce weed problems

Figure 7. Beef cattle feeding in corn stubble. Michelle Cole

Grazing

Mr. Reding and his family currently have 40 head of beef cattle and 42 goats on their farm (Figure 7). During the growing season the animals intensively strip graze forage fields using a 21- to 28-day rotation. During the winter and early spring they strip graze popcorn stubble; first the cattle and then the goats. By strip grazing they get a lot more time out of the corn stalks because the animals do not stomp in the fodder by walking around searching for corn. Mr. Reding has noticed that the animals prefer the weeds (and forages) they were raised with. Though his cattle do not eat Canada thistle foliage, but they do nip off the flower heads (Figure 8), preventing seed production and dispersal. The goats eat young Canada thistle plants and also prefer weeds such as ironweed, giant ragweed and multiflora rose. This year grazing for weed control was especially effective. By keeping the goats in the field later into the spring and planting later (because of wet soils), there were less weeds in this years soybeans compared with previous years.

Figure 8. Flower heads of Canada thistle are a preferred food source for cattle at Langeland Farms. Erin Taylor

"I had one field that was in popcorn for two years, soybeans, then back to popcorn and that is the first time since I've been organic that I've had giant ragweed. It all has to do with the rotation." – Gary Reding

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Chapter 6

Thresholds: How Many Weeds Are Too Many?

Author: Christy Sprague

Weeds are one of the most costly pests in crop production. Cost effective weed management requires knowing when and if weeds need to be controlled. Weed thresholds are one tool farmers can use when making informed weed control decisions. Webster defines "threshold" as the point at which a stimulus is just strong enough to produce a response. For weed thresholds the "responses" are changes in crop yield and market value. The "stimuli" that can effect these responses are: weed species (some weed species are more competitive than others), weed densities (the more weeds in a field, the more competitive the weeds are), the duration of weed interference (when and how long the weeds are in the field), and the cost of the weed control strategies.

Weed thresholds can be divided into two categories, "Competitive" and "Economic". Throughout this chapter we will look at how competitive and economic thresholds can assist farmers in making informed weed management decisions.

Competitive thresholds

Competitive thresholds can be defined as the total weed density and the duration of interference above which crop yield is reduced to an unacceptable level (Oliver 1988). Estimating competitive thresholds can be difficult because several factors can affect how weeds interact with crops. However, weed scientists have developed general guidelines that are useful in making weed management decisions.

Weed densities

The number of weeds or "weed density" that a crop can tolerate without causing a yield loss is a major component of a competitive threshold. For example, corn yields were reduced 10% when one and four common lambsquarters per yard of row were allowed to compete for the entire season in two different years in Michigan (Figure 1). In soybean planted in 30-inch rows, one

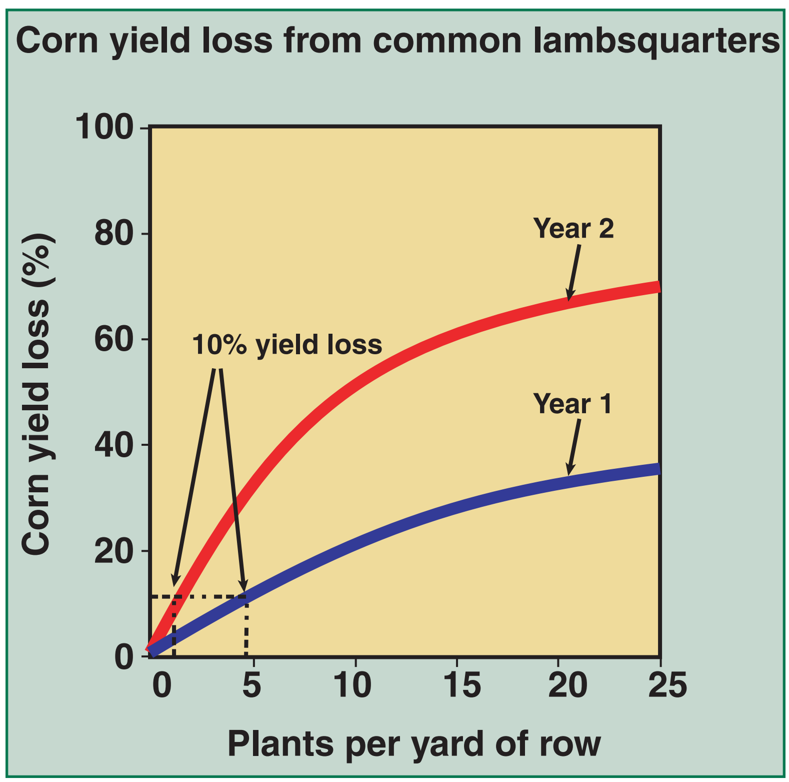


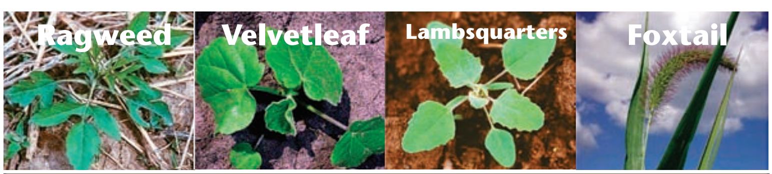
Figure 1. Corn yield loss in two different years from increasing populations of common lambsquarters per yard of row. (Adapted from Fisher et al. 2004)

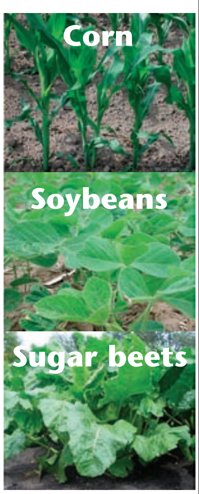
See Chapter 5 in "Integrated crop and weed management" of the MSU Extension Bulletin (E-2931) Integrated Weed Management "One Year's Seeding..." for more information on factors influencing weed competition.

Figure 2. One common lambsquarters plant per yard of row can reduce soybean yield up to 30%. Christy Sprague.

common lambsquarters per yard of row reduced soybean yields 20 to 30% (Crook and Renner 1990) (Figure 2). Soybean is not as competitive a crop with weeds as corn. Weed scientists have developed guidelines for weed thresholds in different crops. These guidelines are estimating the weed densities that lead to a 5- to-10% yield loss. Threshold densities for annual broadleaf weeds emerging with the crop are generally less than six plants per yard^2 in corn and less than one plant per yard^2 in soybean (Swanton et al. 1999). Annual grass threshold densities are higher and have been reported to be between 12 and 48 plants per yard^2 in both corn and soybean. Unlike corn and soybean, small grains are strong competitors with weeds. Therefore, weed thresholds are higher for small grains as compared with row crops. In winter cereals, European researchers recommend threshold levels of 24 to 36 plants per yard^2 for grass weeds and 48 to 60 plants per yard^2 for broadleaf weeds (Gerowitt and Heitefuss 1990). In contrast, threshold levels would be extremely low (approaching zero) for many crops that are weak competitors with weeds. Threshold densities are often less than one plant per yard^2 for sugar beet, potato, and several vegetable crops.

Figure 3. Weeds differ in their competitive ability. Weed densities of giant ragweed, velvetleaf, common lambsquarters and foxtail plants that reduced corn, soybean and sugar beet yields by 25%.





Densities of plants that caused 25% yield reduction

	Ragweed	Velvetleaf	Lambsquarters	Foxtail
Corn	— per 10 yd^2 — 3	— per 10 yd row — 20-90	— per 10 yd row — 40-270	— per 10 yd row — 300-750
Soybeans	1-4	— per 10 yd^2 — 20	16-35	1960
Sugar beets	—	—	4	16-70

Sources: Crook and Renner 1999, Dekker and Megitt 1983, Fausey et al. 1997, Fischer et al. 2004, Harrison et al. 2001, Knake and Slife 1962, Lindquist et al. 1996, Mesbah et al. 1994, Schweizer 1983. Webster et al. 1994.

Weed species

Some weed species are more competitive than others. Common purslane is a low-growing summer annual and is not competitive with tall crops such as soybean or corn. On the other hand, a weed like common cocklebur is tall and has an extensive root system. Common cocklebur is one of the most competitive weed species in corn and soybean production. We can rank the competitive ability of various weed species. Figure 3 provides examples of the competitiveness of four weeds common to the North Central region of the United States. Giant ragweed is more competitive than velvetleaf and common lambsquarters, and all three broadleaf weeds are much more competitive than the foxtails (giant and green). Of course, the relative competitiveness of weeds will vary with both the crop and the environmental conditions in which competition occurs. For example, under hot, dry conditions, redroot pigweed in which does better under cooler conditions.

Figure 4. Fields contain multiple weed species.
Christy Sprague

Multiple weed species

Virtually all fields contain more than one weed species (Figure 4). However, as you can see from earlier examples, much of the weed interference research has focused on the effects of a single weed species on the crop. Developing thresholds for multiple weed species is challenging. For example, the yield loss from a mixture of 20 giant foxtail and 10 common lambsquarters does not equal the yield loss from 30 giant foxtail plants in the same area because the competitive abilities of these two species are not equal (Figure 3). However, one can speculate that yield losses from multiple weed species may be additive. Therefore, if 20 giant foxtail reduced yield 15% and 10 common lambsquarters reduced yield 25% the total yield loss would be 40%. This assumption is complicated by the fact that the weeds not only compete with the crop, but they also compete with each other. We know that at low weed densities the impact of multiple weed species is additive, but at high weed densities this does not hold true (Mesbah et al. 1994; Swanton et al. 1999). Yield loss predictions from weed mixtures at moderate and high densities will be over estimated if we add yield losses from individual species.

Competitive indices (CIs)

A more practical approach to estimating crop yield losses for fields with multiple weed species is by ranking weeds in terms of their competitiveness against the crop. These weed "rankings" are called competitive indices. Weeds are ranked on a scale from zero (not competitive) to ten (most competitive).

Table 1. Examples of corn and soybean competitive indices. Weeds with a competitive index of 10 are the most competitive.

Broadleaf weeds	Comp. Indices	Grass/Grass-like weeds	Comp. Indices
Giant ragweed	10.0	Johnsongrass	2.5
Common cocklebur	5.0	Volunteer corn	2.0
Velvetleaf	4.0	Quackgrass	1.5
Common lambsquarters	3.5	Barnyardgrass	1.0
Common ragweed	3.5	Giant foxtail	1.0
Jimsonweed	3.0	Green foxtail	1.0
Dandelion	2.0	Yellow foxtail	1.0
Powell amaranth	2.0	Yellow nutsedge	1.0
Common waterhemp	2.0	Large crabgrass	0.8
Redroot pigweed	2.0	Fall panicum	0.8
Kochia	2.0	Field sandbur	0.5
Pennsylvania smartweed	2.0	Witchgrass	0.5
Canada thistle	2.0		
Field bindweed	1.0		
Horseweed	1.0		
Eastern black nightshade	0.5		

The most competitive weed is used as the reference species, and all other species are assigned a competitive index value in relation to the reference species. These values are based on previous research and expert opinions. Table 1 is a listing of competitive index values for weeds common to the upper Midwest.

Mesbah et al. (1994) found that sugar beet yield losses from low mixed densities of kochia and green foxtail were additive. This indicates that at lower densities kochia and green foxtail had minimal effects on each other. However, at higher densities (seven green foxtail and two kochia per yard of row) results were not additive.

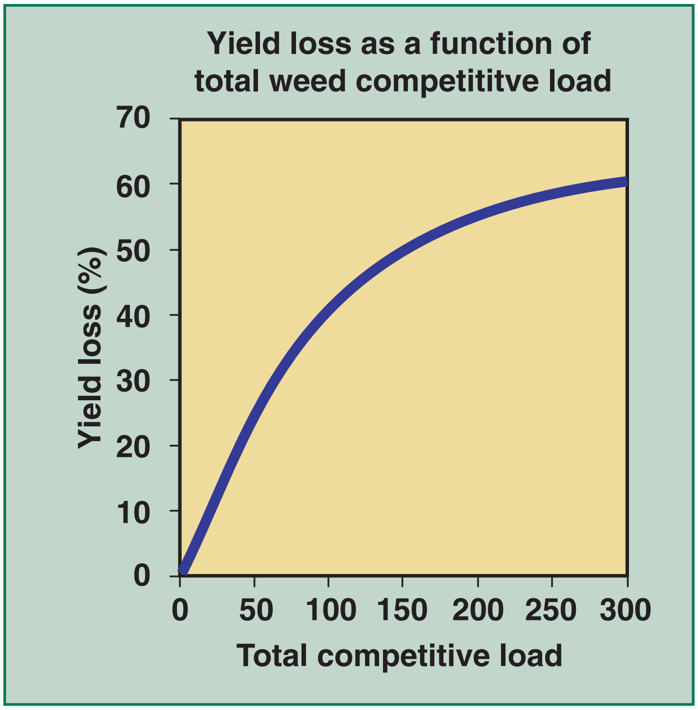


Figure 5. Yield loss as a function of total weed competitive load. Total competitive load is the sum of the weed densities of individual weed species multiplied by their competitive indices. (Adapted from Coble and Mortensen 1992)

The competitive index values are multiplied by the density of each individual weed species and then these values are summed to give a Total Competitive Load that can be used to estimate crop yield loss (Coble and Mortensen 1992) (Figure 5). Total competitive load models are often used in computerized decision support systems such as WeedSOFT and HERB.

Duration of interference or "critical period of competition"

Crops can tolerate weeds for a certain period of time without suffering yield loss. This time period is known as the "critical period of competition" (Figure 6a and b). Understanding critical periods of competition are important for timing postemergence weed control applications, cultivation, or bringing labor in for hoeing weeds.

Critical periods of competition are not the same in all crops and are going to vary somewhat depending on the weed species and weed number, the crop row spacing, and the weather. Here are a few examples. In Illinois, corn tolerated high common waterhemp populations until the V4 growth stage (four leaves showing full collars; about seven leaves showing in all) when there was plentiful rainfall (Figure 7). However, in years when rainfall was not adequate, corn yield was reduced if common waterhemp was not managed prior to the V4 corn stage (Steckel and Sprague 2004a). Because rainfall is not predictable the competitive threshold for common waterhemp in corn should be management prior to V4 corn! The critical period for competition can also change with weed density. In Ohio, Harrison (1990) found that common lambsquarters' competitive thresholds in 30-inch row soybean were two plants per yard of row for five weeks after soybean emergence. When there was only one common lambsquarters plant per yard of row, the critical period for competition was extended until seven weeks after soybean emergence.

Researchers have defined critical periods of competition by crop stage, weed height, and days/weeks after planting. While there is much debate on which is the best indicator, generalizations can be made on the critical periods of competition for several crops. Table 2 is a compilation of the critical period of competition for several crops grown in the upper Midwest.

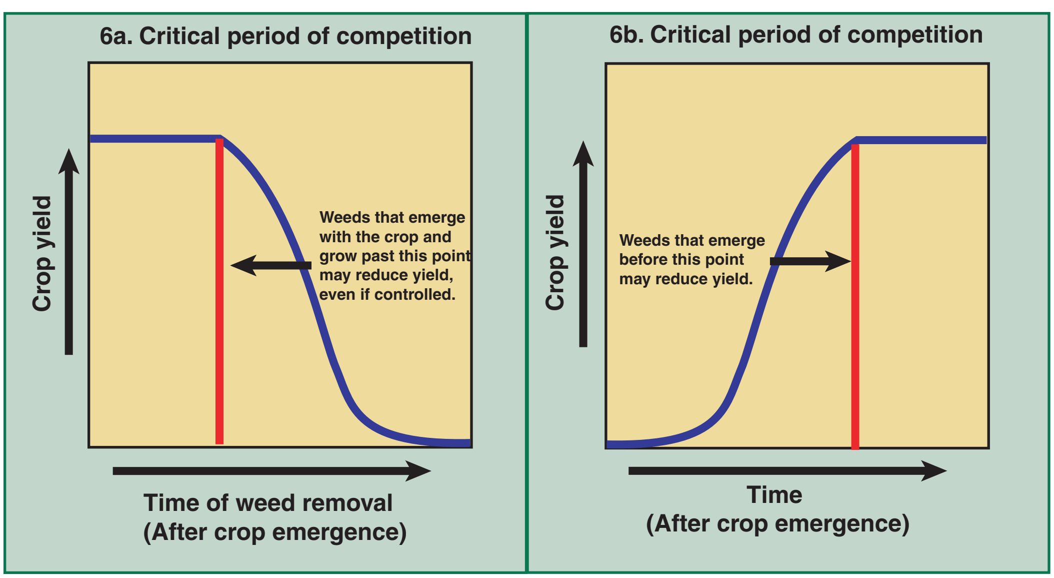


Figure 6 a and b. Critical period of competition.

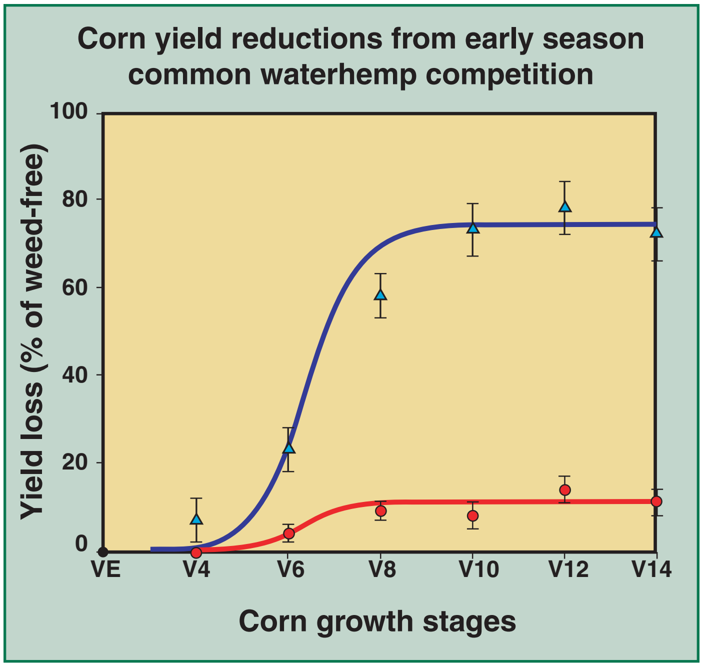


Figure 7. Corn yield reductions from early season common waterhemp competition. The critical period of competition was different in year 1 (blue line) compared with year 2 (red line) because rainfall was less in year 1. (Adapted from Steckel and Sprague 2004a)

Table 2. Weeds should be controlled prior to the critical periods of competition.

Crop	Critical period of competition
Carrots	5 weeks after emergence
Corn	3 weeks after planting
Dry edible beans	3 weeks after planting
Green beans	4 weeks after seeding
Lettuce	3 weeks after 50% emergence
Onions	4 to 6 weeks after emergence
Pickling cucumbers	2 weeks after emergence
Potato	4 to 6 weeks after seeding
Soybean	4 weeks after planting
Sugar beet	6 to 7 weeks after planting
Transplanted tomatoes	2 weeks after transplanting

Source: Burnside et al. 1998, Friensen 1978, 1979, Gower et al. 2003, Kemp and Renner 2008, Mulugata and Boerboom 2000, Wicks and Wilson 1983, Roberts 1976, Zimdahl 1980.

If weeds are not controlled prior to the critical period of competition, crop yields will likely be reduced.

However, in many vegetable and organic crops growers start weed control right after planting. In these systems there comes a point when later emerging weeds no longer threaten crop yield. This period is call the "critical weed-free period". Figure 6b illustrates this concept. For example, in sunflower, weeds emerging four to six weeks after seeding did not reduce yield (Zimdahl 1990).

Economic thresholds

Economic thresholds take competitive thresholds one step further by examining the economic value of a weed control decision. An economic threshold is defined as the weed infestation at which weed management costs equal the value of the recovered crop yield (Maxwell and O'Donovan 2007). Economic thresholds can help predict the economic returns of weed management under different situations. For example, if weed populations are low and below the economic threshold there is no financial incentive to spend money on weed control. However, when weed populations exceed the economic threshold the cost of weed management is more than offset by the return on investment because crop yield will increase.

*Net return = (yield*commodity price) – (weed control costs)*

Economic thresholds can be calculated by determining when the net return of a given weed control strategy is equal to the net return without weed control.

Figure 8 is a graphical interpretation of an economic threshold. From this example, the economic threshold is 15 plants per yard^2. If the weed density is below 15 plants per yard^2 money would be lost by implementing the selected weed control strategy. However, if the weed density is greater than the economic threshold of 15 plants per yard^2 there would be an increase in net returns if the decision was made to use the selected strategy for weed control.

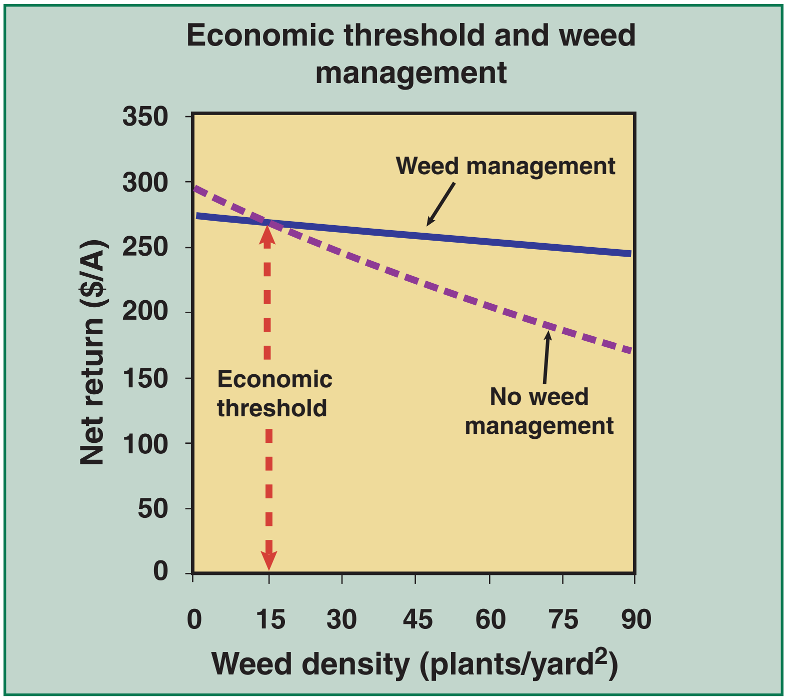


Figure 8. The economic threshold is the weed density where the net return with weed control is equal to the net return with no weed control. (Adapted from Maxwell and O'Donovan 2007)

Economic thresholds can also be calculated by using the equation below (Coble and Mortensen 1992).

From this equation, it is apparent that economic thresholds are not only dependent on estimations of crop yield loss and weed control, but are closely tied to the value of the crop (weed-free yield*commodity price) and the cost of weed control. Fluctuations in crop values and weed control costs can have a large impact on economic thresholds. Higher crop values would lead to lower economic thresholds, where as higher weed control costs would lead to higher economic thresholds. Therefore, the calculation of economic thresholds allows for the assessment of several different management strategies based on the weed infestation in a field and the expected weed control from a given management strategy.

One of the criticisms with using economic thresholds is decisions are based on a single season. Economic thresholds do not account for weed seed production and future problems if weeds are below threshold levels and the decision is made not to control the weeds. For example, relatively low infestations of weeds that are not managed could produce enough seed to maintain weed populations above economic thresholds for several years (e.g. common lambsquarters is capable of producing over 72,000 seeds per plant if left uncontrolled for a single season). However, there have been some attempts to model the implications of weed seed production in economic thresholds. This concept is referred to as "economic optimum thresholds" (Cousens 1987).

Economic optimum thresholds

By accounting for the costs associated with weed seed production, economic optimum thresholds offer decisions that provide the greatest net benefit over a long term (Cousens 1987). These thresholds combine yield loss models from economic thresholds with weed seed production models. In many cases, economic optimum thresholds can be four-times lower than single season thresholds, because they account for future impacts of seeds produced by weeds that are not controlled (Cousens 1987). Weed seed production and long seed persistence will cause problems in farm fields in the future. For example, Bauer and Mortensen (1992) determined that the economic optimum threshold was 7.5-fold lower for velvetleaf in soybean and 3.6-fold lower for common sunflower than the economic threshold (Table 3). Velvetleaf produces larger quantities of seed with greater longevity, where as seed produced by common sunflower is less persistent and prone to predation. Velvetleaf therefore has a lower economic optimum threshold compared with sunflower. One of the difficulties in estimating economic optimum thresholds is the lack of information on the long-term influence of crop rotations and other management practices on weed interference, weed seed production and weed seed fate.

$$\textit{Economic threshold} = \frac{\textit{Weed control costs}}{\textit{Weed-free yield*Commodity price* Yield loss}^{a}\textit{*Weed control}^{b}}$$

[a]Proportional yield loss per unit weed density.
[b]Proportional reduction in weed density from the weed control strategy.

Table 3. Economic and economic optimum thresholds for velvetleaf and common sunflower in soybean. Economic optimum thresholds account for more than a single season and are generally lower than economic thresholds.		
	Economic threshold	Economic optimum threshold
	— Plants per 10 yard^2 —	— Plants per 10 yard^2 —
Velvetleaf	3.1	0.4 to 0.5
Common sunflower	1.8	0.5
Source: Bauer and Mortensen 1992.		

Effectiveness of weed thresholds

Time of weed emergence

Most weed-crop interaction models do not consider the time of weed emergence when estimating competitive and economic thresholds. Threshold levels for weeds that emerged three to four weeks after the crop were two to ten times higher than threshold levels for weeds that emerged with the crop (Figure 9) (Swanton et al. 1999). Other studies have shown that delaying weed emergence three to five weeks after crop planting was long enough to prevent significant yield loss in corn and soybean (Hall et al. 1992, Van Acker et al. 1993). If the time of weed emergence is not considered, threshold levels based on weeds emerging at the same time as the crop will overestimate the need for control of later emerging weeds.

Figure 9. Threshold levels for common ragweed that emerged three weeks after dry beans were 2-times higher than thresholds for common ragweed that emerged with the crop. (Source: Chikoye et al. 1995) 📷 **Christy Sprague**

Weeds left in the field

Weed populations below competitive or economic thresholds will result in weeds left in the field at the end of the season. While these weeds may not have an effect on this year's crop, they can impact the harvestability of the crop (Figure 10), degrade the marketability of the crop (Figure 11), and add stress to landlord-tenant relationships (Figure 12).

Figure 10. Weeds can cause problems with harvest. 📷 **Jeff Bunting**

Figure 11. Eastern black nightshade berries harvested with soybeans can cause major dockage at the elevator.

Figure 12. Weeds in fields strain landlord-tenant relationships. Christy Sprague

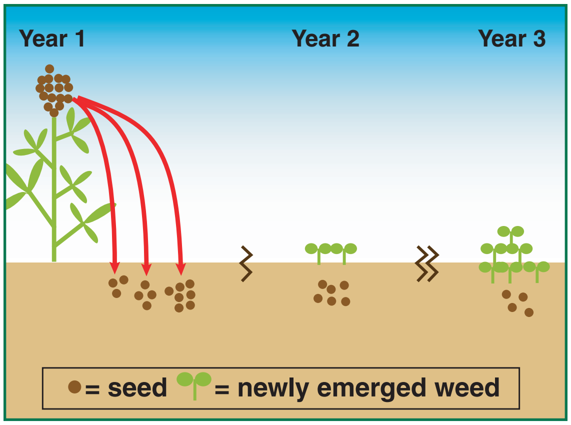


Figure 13. Seed produced from uncontrolled weeds impact future crops.

More importantly below threshold weeds are capable of producing seed that replenish the soil's weed seed bank and perpetuate weed infestations into the future (Figure 13). Table 4 provides examples of potential weed seed production from early and late emerging weeds.

Management of weed escapes

Competitive and economic thresholds allow for the production of seed when weeds are at or below threshold levels.

Competitive and economic thresholds should not be used when weed species are new to fields, reduce crop quality, or are difficult to control in other crops in the rotation. Norris (1999) proposed a "no-seed threshold" for these situations.

While no seed thresholds may be unrealistic for most growers, there are some growers in California that have used this strategy. These growers have successfully been able to use non-chemical weed control techniques to reduce the overall weed populations on their farms.

Table 4. Weed seed production of early- and late-emerging weeds. Note how late-emerging weeds produce fewer seeds compared with weeds that emerge with the crop.

Weeds	Crops	Emergence with the crop	Late emergence	Difference in emergence	Seed production
		seeds/plant	seeds/plants	weeks/stages	% reduction
C. lambsquarters	No crop	6,630	160	6 weeks	41
C ragweed[a]	Dry beans	7,200	1,200	VE to V3	
C. waterhemp	Corn	3,000-16,000	90-1,200	VE to V6	93-97
C. waterhemp	Soybean (30-inch rows)	23,000	4,300	VE to V4	81
C. waterhemp	Soybean (7.5-inch rows)	26,000	500	VE to V4	98
Giant ragweed	Corn	1,900	8	6 weeks	99
Giant ragweed	Soybean	5,500	1,200	6 weeks	78
Powell amaranth	Broccoli	6,000-57,000	0-5,000	10 days	91-100
Velvetleaf[a]	Corn	2,583	1,028	3 weeks	60
Wooly cupgrass	No crop	12,000	3,000	6 to 8 weeks	75

Sources: Bello et al. 2000, Cardina et al. 1995, Chikoye et al. 1995, Maertens 2003, Mulugeta and Stoltenberg 1998, Steckel and Sprague 20045a,b.
[a]Seed production for common ragweed and velvetleaf is on a per yard^2 basis.

Figure 14. Common purslane and other weeds can reroot under wet condition. Christy Sprague

Strategies that may be used to control weed escapes and reduce seed production include chemical control and non-chemical control techniques such as cultivation, hand-hoeing, and hand-pulling of weeds. The basic principle behind the non-chemical strategies is to uproot weeds. The effectiveness of uprooting weeds is strongly dependent on soil moisture (Cloutier and Leblanc 2001). When weeds are uprooted in dry soils they die by desiccation. However, under wet conditions many more weeds survive because weeds reroot. Common purslane, pigweeds, smartweeds, and large crabgrass are all weeds that are likely to reroot (Figure 14).

Weeds that are uprooted by cultivation or hand-weeding may still produce viable seeds. Seed maturation on cut shoots is dependent on the weed and its stage of maturity. Table 5 lists examples of weeds that are able to produce viable seed when cut or pulled at various stages of maturity (Figure 15). Precautions must be taken to ensure that weed removal is done early enough to prevent the maturation of seeds on cut shoots. Weeds that are approaching seed maturity (seed at milk/fruit stage) should be removed from the field to eliminate the introduction of new viable seed. However, there has been research that has combined uprooting and additional control tactics to reduce weed seed production. In common purslane a combination of flaming or applications of glyphosate on uprooted purslane reduced seed set (Harr and Fenimore 2003).

Table 5. Seeds will continue to mature on plants that are cut down or pulled prior to seed maturity. Germination of weed seeds from plants that were cut down near the base of the plant at various stages of plant/seed maturity.

Weed	Bud stage	Flowering stage	Milk/Fruit stage	Mature seeds
	% germination			
Annual sowthistle	0	100	—	100
Canada thistle	0	0	—	38
Common chickweed	—	0	55	60
Common groundsel	0	35	—	90
Corn speedwell	—	0	67	68
Curly dock	—	0	88	84
Dandelion	0	0	—	91
Jimsonweed	—	0	100	100
Meadow barley grass	—	0	90	94
Shepherd's-purse[a]	0	0	82	89
Soft brome grass	—	0	81	96
Stinging nettle	—	0	70	77

Adapted from; Gill 1938.
[a]Sheperd's-purse seeds were divided into four groups: small green, medium green, large green and mature. Germination only occurred from seeds that were large green and mature.

Figure 15. Jimsonweed can still produce viable seed once the seed is in the milk stage (above) even if the plant is pulled or cut down prior to seed maturity. Christy Sprague and Erin Taylor

Table 6. Common purslane seed production from plants uprooted 6 weeks after emergence and then exposed to flaming, glyphosate application or crushing by tractor tires.

Weed control tactic	Seed production
	— % reduction —
Flaming	92-94
Glyphosate (2% v/v)	82-92
Crushed	25-57

Adapted from: Harr and Fenimore 2003.

Seed set was also reduced when uprooted plants were crushed with the tractor tires but not to the same extent as flaming or glyphosate applications (Table 6). Herbicide applications to actively growing plants approaching seed maturity also reduce weed seed production and subsequent germination (Table 7).

Decision support tools

Several computerized decision support systems have been developed utilizing different aspects of competitive and economic thresholds.

One computerized decision support system used in the North Central Region is WeedSOFT. This online program http://www.weedsoft.org helps producers assess what impact different weed populations have on crop yield and the subsequent dollars lost if a weed control strategy is not implemented. Different control strategies can also be compared to determine what may be the most cost effective program to manage the weeds. Similar to weed thresholds, WeedSOFT should be a decision support system and not a decision tool.

Table 7. Seed production and subsequent emergence of common cocklebur seeds produced from plants that were treated with glyphosate at three different stages of seed development.

	Seeds per plant	Seedling emergence
	— % reduction —	— % of untreated —
Initial seed set	71	3
Mid-seed set	7	45
Mature seeds	0	77

Adapted from: Clay and Griffin 2000.

Chapter 7

On-farm Weed Management Trials Across the North Central Region

Author: Erin Taylor

Introduction

In 2004 a working group of researchers, extension educators, and growers came together to create the Michigan State University Extension (MSUE) bulletin "Integrated Weed Management 'One Year's Seeding…'" (IWM). The bulletin was released in February 2005 to fulfill the lack of information readily available on sustainable weed management. In 2006 and 2007, ten on-farm trials were conducted on farms across the North Central region as a part of the same NCR-SARE grant that funded the creation of the bulletin. These trials were all held on certified organic farms and were designed by the growers to examine integrated weed management techniques. Four of the ten trials were conducted in Michigan, three were conducted in Illinois, two in Iowa, and one in Wisconsin. Some results may vary based on local environmental conditions.

Effects of corn planting time on weeds

Good Hope, IL

Grower questions: ***What impact does corn planting time have on weed populations? Are there any other important impacts?***

Methods

Twenty acres were planted to organic, food-grade corn in Good Hope, IL to examine the effects of 3 planting dates on the weed community and corn yield. The experiment was arranged in a randomized strip-plot design with 3 treatments. These treatments include: 1) Early Planting Date (~2 weeks early), 2) Average Planting Date (On-time), and 3) Late Planting Date (~2 weeks late). Due to heavy rains, the planting times did not go exactly as planned for the On-time and Late plantings. Observations on weed and insect pressure were recorded throughout the season.

Figure 1. From left to right: Corn rootworm larvae, adult female, adult male and . corn silk clipping due to adults Marlin E. Rice, Kathrin Schirmacher (adults), R.L. Nielson

Table 1. Field operation and corn development dates and yield for Good Hope, IL.			
Treatment	**Early**	**On-time**	**Late**
Planting date	May 18	June 7	June 15
Cultivation dates	May 26 June 19 June 28	June 28	July 8
Canopy closure	June 28	July 6	July 15
50% Tassel emergence	July 10	July 30	August 5
50% Silk emergence	July 11	July 31	August 4
Corn yield (bu/A)	106	42	36

Results

Weeds were counted in mid-July and mid-September. At these times, there was no significant difference in broadleaf or grass populations across the three planting dates. Corn yields in the early planting were higher than the on-time and late plantings. The grower attributed a portion of the yield loss to high temperatures during the later two pollination windows.

Grower comments

Severe cutworm damage was observed in 3 of the 4 reps. for the early planting time. In late-June the early planted corn appeared to have more weed pressure than the late planted corn. The late and on-time plantings had fewer weeds perhaps because of later tillage prior to planting. The on-time and late plantings had severe silk clipping due to corn rootworm beetles. European corn borer pressure was significant in all plantings, however, few ears dropped.

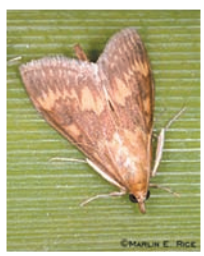




Figure 2, 3 and 4 (left to right). European corn borer larvae, adult and ECB larvae in ear shank. Marlin E. Rice

Figure 5. In late June the early planted corn (left) appeared to have more weed pressure than the late planted corn (right).

Figure 6. Corn planted early (left), late (center) and on-time (right).

Intercropping for weed control in corn

Alma, MI

Grower question: ***How does intercropping with Green-N-Gold (a mix of two legumes, a grass and a brassica species) affect weed control and corn yields?***

Methods

A two year study was conducted in Alma, MI. Organic corn was planted on April 29, 2006 at approximately 26,000 seeds per acre and June 1, 2007 at 30,200 seeds per acre. Each year, when the corn was about knee high (June 25, 2006 and July 2, 2007), two strips of the Green-N-Gold mix (Michigan mammoth red clover, ryegrass, oilseed radish, and hairy vetch) were broadcast over the corn at average rates of ~34 lbs. per acre in 2006 and 53 lbs. per acre in 2007. Weed counts were taken before and after cover crop emergence. At the end of the season cover crop biomass was recorded and corn was harvested. The following spring, the overwintered cover crop biomass was recorded. In Alma the 30-year precipitation average between June and November is 19 inches.

Figure 7. Green-N-Gold mix contains Michigan mammoth red clover, ryegrass, oilseed radish and hairy vetch seed (left to right).

Figure 8. Green-N-Gold mix seedlings six weeks after planting (Clockwise from top left: Mammoth red clover, ryegrass, oilseed radish, and hairy vetch).

Results

At the end of the 2006 season, the Green-N-Gold cover crop mix produced 2,900 lbs. per acre of dry biomass. The following spring the Green-N-Gold mix was still growing, with 2,800 lbs. per acre (i.e. dry biomass) present before incorporation in May. Though the oilseed radish winter-killed, the other species made up the difference. In 2007 the Green-N-Gold biomass at the end of the season was 4,300 lbs. per acre, however due to low rainfall in the spring, dry biomass prior to incorporation in 2008 was only 800 lbs. per acre. One to three months after planting Green-N-Gold there were significantly less broadleaf weeds where the cover crop was present (figure 11). Grass densities were low overall and no differences were observed. No significant differences in corn yields were found between the cover crop and no cover crop treatments. Average corn yield was 100 bushels per acre in 2006 and 132 bushels per acre in 2007.

Figures 9 and 10. 2006 Green-N-Gold mix remaining in May 2007; no oilseed radish remains (left). In the fall oilseed radish flowers (right) were common in areas where there were breaks in the corn canopy. Seeds formed can persist for several years. This is also a risk with hairy vetch if not controlled when flowering in spring.

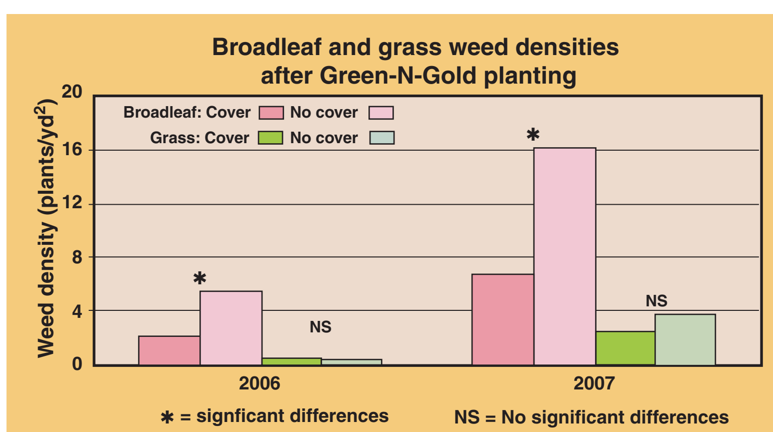


Figure 11. In both 2006 and 2007 there were significantly less broadleaf weeds in the Green-N-Gold intercrop treatment compared with the no cover treatment one month or more after intercrop seeding. There were no differences in grass densities.

Intercropping with buckwheat and oats in corn

North Branch, MI

Grower question: ***Can intercropping maintain yields, while reducing weed density in open-pollinated corn?***

Methods

J-Reid's Yellow Dent open-pollinated corn does not tolerate populations over 16,600 plants per acre. Planting at such a low density favors weed growth. In North Branch, MI buckwheat, oats, or a combination of the two were inter-planted on one-third of the corn acreage for ground cover in an effort to reduce weed densities. In this manner the in-row corn populations could be higher (i.e. 25,000 plants per acre), but the actual population would remain at 16,650 plants per acre. This was achieved by putting the cover crop seed in the 2nd and 5th boxes of a six-row planter (Figure 13). Using this method corn and cover crops were planted simultaneously on June 12, 2007. For comparison, plots with solid corn were also planted at populations of 25,000 plants per acre and the standard 16,600 plants per acre. During the season weed and corn densities were recorded twice (July 11 and September 14). Twenty-five foot sections of corn were harvested by hand from each treatment. The number of ears per plant were also recorded and nutrient analysis was conducted on the grain. The 30-year precipitation average between June and November in North Branch is 19 inches.

Figure 12. Buckwheat (left), combination buckwheat and oats (center) and oats (right).

Table 2. Planted and actual densities for the corn in each treatment.

Treatment	Planting density (plants/A)	Actual density (plants/A)
16,600 plants/A	16,600	15,334
25,000 plants/A	25,000	19,516
Buckwheat	16,500	11,789
Oats	16,500	14,171
Combination	16,500	12,138

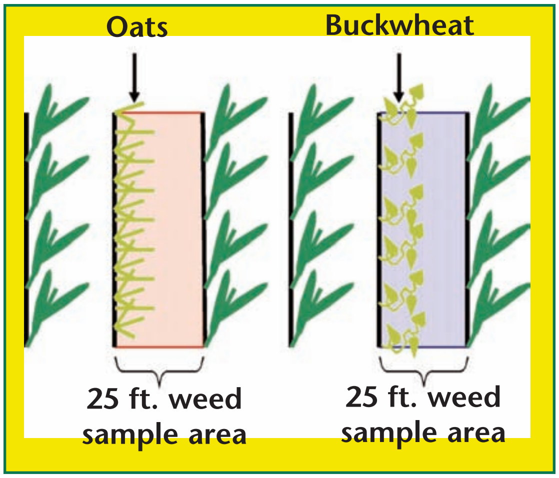


Figure 13. Oats and buckwheat were planted simultaneously with corn by putting them in planter boxes 2 and 5.

Figure 14. Buckwheat growth as of September 14, 2007.

Results

In July, the combination of buckwheat and oats and the 25,000 plants per acre treatments significantly reduced weed densities compared to the 16,600 plants per acre standard (data not shown). By September, the cover crop combination of buckwheat and oats and the buckwheat only treatments reduced weed densities better than all others (Figure 15). All cover crop treatments had similar yields, averaging 65 bushels per acre. This was significantly lower than both the 25,000 plants per acre (76 bushels per acre) and the 16,600 plants per acre (109 bushels per acre) treatments. In all treatments the average ear production per plant was one and there were no nutrient differences. Though intercropping with buckwheat or a combination of oat and buckwheat reduced weed densities, the decreased corn acreage reduced yield.

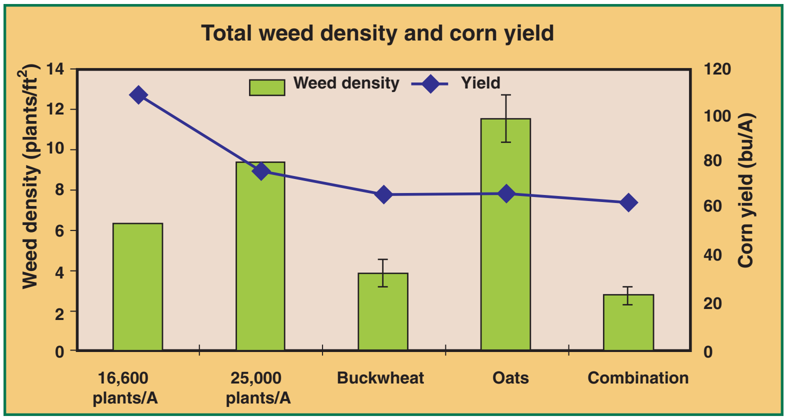


Figure 15. Total weed density at the September 14, 2007 sample date and corn yield.

Cover crops for Canada thistle suppression

Maple Park, IL

Grower question: ***Can buckwheat, cowpea or sundangrass deter the growth of Canada thistle?***

Methods

In July of 2005, buckwheat, hybrid sudangrass and cowpea were planted at seeding rates of 108 lbs. per acre, 35 lbs. per acre, and 45 lbs. per acre, respectively, to reduce Canada thistle populations in Maple Park, IL. Fallow areas in the alley ways were also left at this time to allow for comparisons. Rye was planted at 135 lbs. per acre in early November following the chopping of cowpea and sudangrass, harvest of buckwheat, and disking and cultivating of the field.

In 2006 the effect of these cover crops and the fallow treatment were examined more closely for their relative impacts on Canada thistle populations. On May 22, 2006 the rye was chopped. The rye was tilled on May 27 and plowed under on June 7. The field was then disked and twice cultivated before planting organic buckwheat in late July. The experiment included 4 treatments based on the cover crop grown the previous summer (2005). The 4 treatments were buckwheat, sudangrass, cowpea and no cover (fallow). There were 4 replications.

Canada thistle plants were counted in designated sample areas on August 26, September 15 and November 8, 2006. Each treatment had two sample areas, measuring 10 ft. by 3 ft. Each sample area was representative of the overall Canada thistle population within the treatment. Throughout the course of the experiment visual observations were made regarding the impact of the cover crops on Canada thistle populations. The buckwheat was harvested on November 9, 2006.

Figure 16. Canada thistle growing in June 2005 prior to cover crop planting.

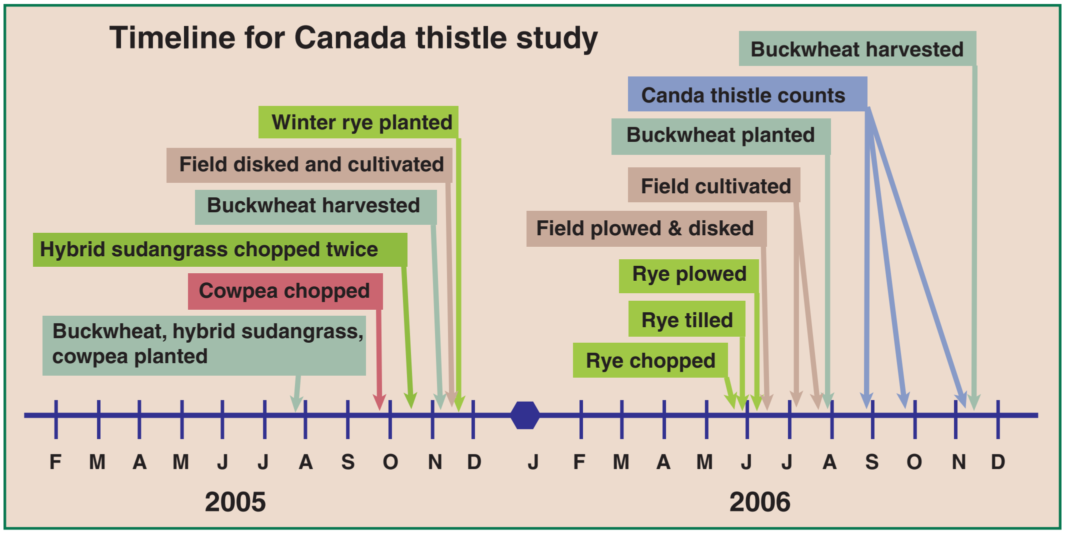


Figure 17. Timeline for the Canada thistle study in Maple Park, IL.

Figure 18. Fallow (center), buckwheat (sides) and sudangrass (back) treatments in Sept. 2005.

Results

There were no significant differences in Canada thistle populations among cover crop treatments at any of the sampling dates though there may have been differences in biomass, which was not measureed. Though the difference was not statistically significant, the grower was pleased with thistle suppression by sudangrass and buckwheat (See comments).

Grower comments

My suggestions are the following: “A) Cowpeas: Do not plant due to poor germination in the summer, B) Fallow: Not very effective; not agronomically sound either, C) Buckwheat: Has some merit, especially if an entire field has a light to moderate thistle infestation. It also provided me with an income of approximately $250 per acre; this is assuming good quality and good marketing as well. Planting buckwheat in late July also allows for a couple of trips with the field cultivator during early-mid summer, D) Sudangrass—most effective! In less than 3 months the sudangrass reached 6- to 9-ft. tall. There was so much sudangrass biomass generated in a short period of time that the thistle, which had already been knocked down by repeated summer cultivations, was probably both starved and smothered. I would recommend planting sudangrass for use in a highly thistle infested field.”

Figure 19. Canada thistle growing in buckwheat in September 2005.

Figure 20. Canada thistle growing in buckwheat stubble in November 2006.

Mulches for common purslane control in tomato

Urbana, IL

Grower question: ***Can mulches reduce weed germination and growth in tomatoes? Are some mulches more effective than others?***

Methods

Three 300 foot rows (200 plants each) of 'Viva Italia' tomatoes were transplanted on June 15, 2008 in Urbana, IL to study the effects of mulches on weed germination and growth. Rye straw and buffalo grass clippings were each spread by hand 2 to 3 inches thick around the tomatoes on July 4, 2008. One treatment was left bare for comparison. During the season weed densities and biomass were recorded. Common purslane, the most common weed in this field, has a light requirement for germination, therefore the amount of photosynthetically active radiation (PAR) reaching the soil surface was recorded in all of the treatments. Yields were recorded at each harvest. In addition to the field experiment, the two mulches were studied in the laboratory to determine if chemicals released during mulch degradation reduced plant growth.

Figure 21. Photos taken August 16 (i.e. approximately 6 weeks after mulch application) revealed that the mulches suppressed weed populations. Top: No mulch; middle: Rye straw; bottom: Buffalo grass.

Figure 22. Comparative tomato yields for the rye straw, buffalo grass and no mulch treatments.

Results

Both mulches significantly reduced weed populations. This reduction was likely due to the reduction of PAR reaching the soil surface in the mulched plots (data not shown). Tomato yield was greater in the mulched treatments because there was less weed competition and less water lost by evaporation. The increase in yield more than covered the costs associated with applying the mulch. When examined in growth chambers, buffalo grass residues reduced lettuce germination by ~65% compared with lettuce grown without residues. This indicates that buffalo grass could be exuding allelopathic chemicals that may help reduce weeds.

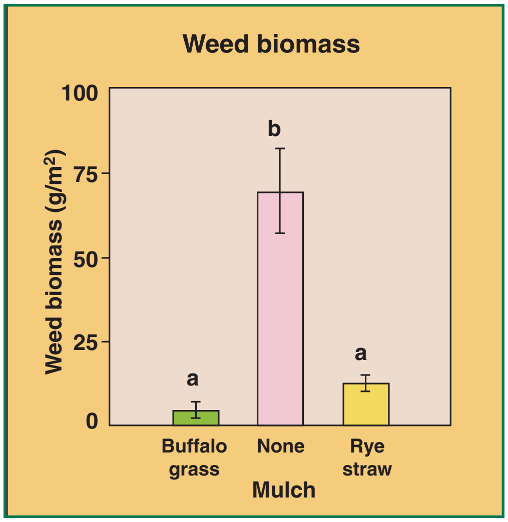


Figure 23. Weed biomass in each treatment. Different letters represent a significant difference.

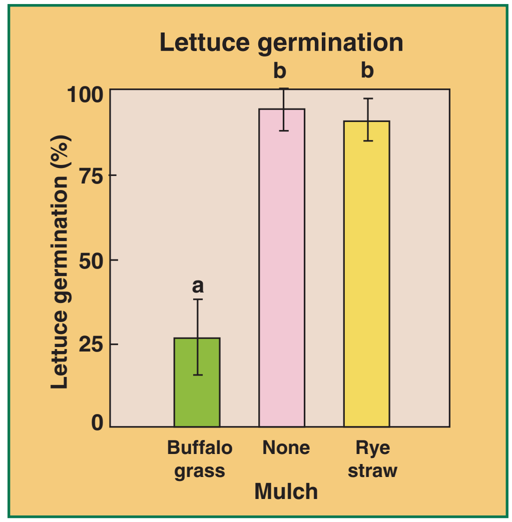


Figure 24. Percentage of lettuce seeds that germinated in the presence of the mulches. Different letters represent a significant difference.

Ridge-till vs. conventional-till in soybean

Harlan, IA

Grower questions: ***Is there a difference in ridge tillage and conventional tillage systems with respect to weeds in soybean?***

Methods

Ridge tillage dries the soil quickly, allowing for earlier soybean planting dates. Conventional (disk) tillage on the other hand dries the soil more slowly, which delays planting but allows more weeds to be controlled before planting. To answer the question as to which systems approach provides better weed control, six acres were planted to organic soybean in Harlan, IA in 2007. The treatments (and planting dates) were as follows; 1) early ridge-till (May 14), 2) middle ridge-till (May 21), and 3) conventional tillage (May 28). In all treatments the BlueRiver 2A71 soybeans were planted at a population of 175,000 seeds per acre. Following planting all plots were rotary hoed and cultivated an equal number of times. Hand weeding was done between July 31 and August 9. Broadleaf weeds were counted at the time of hand weeding. Yields were recorded for each treatment at harvest.

Results

The conventional tillage system had significantly more weeds (2.5 to 4.5 times more) than the early and middle ridge-till treatments. Because of the differences in weed densities among treatments the time to hand weed varied from 1 to 4 man hours per acre. Soybean yields were greatest in the early ridge-till treatment (59 bushels per acre) followed by middle ridge-till (56 bushels per acre) and conventional tillage had the lowest yield (54 bushels per acre).

Figure 25. The two ridge-tillage treatments were planted earlier (top left) than the conventional tillage treatment (top right). All plots were rotary hoed twice using a John Deere hoe (bottom left) and cultivated three times using a Buffalo cultivator (bottom right).

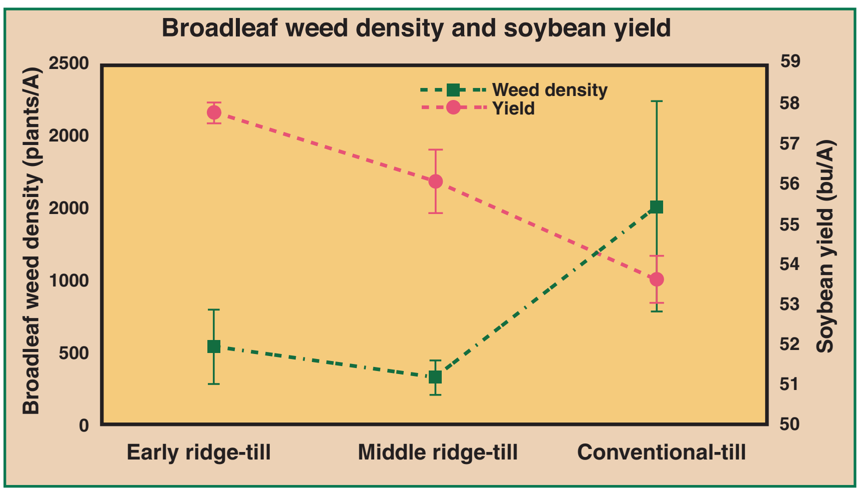


Figure 26. Broadleaf weed densities (dark green) and soybean yields (red) based on the tillage and planting treatment.

Cultivator comparisons for weed management

Schoolcraft, MI

Grower question: ***Which cultivation implements work best for early- and mid-season weed control in soybean?***

Methods

For this two year study, organic soybeans were planted on May 9, 2006 and May 15, 2007 in Schoolcraft, MI. The soybeans were planted in 30-inch rows at a population of 165,000 seeds per acre. There were 2 treatments. Treatment 1 was weeded three times using a tined implement early in the season and cultivated three times using a Danish tined cultivator mid-season. Treatment 2 was rotary hoed three times early in the season and cultivated using a Lilliston cultivator three times later mid-season. Early season cultivation (tined weeder vs. rotary hoe) took place mid-May to early-June and the later season cultivation (Danish tined weeder vs. Lilliston cultivator) occurred early-June to early-July. Broadleaf and grass weed densities were sampled after early season control, after mid-season control, and again one month after field activity ceased.

Figure 27 and 28. Mid-season weed control: Danish tined weed (left) and corresponding soybean treatment in 2007.

Figure 29. Mid-season weed control: Lilliston cultivator (above) and corresponding soybean treatment in 2007.

Results

There were no significant differences among cultivation treatments for broadleaf or grass weeds at any sample date in 2006. In 2007, the tined weeder did not effectively control weeds due to remaining corn stubble; therefore, all plots were rotary hoed for early season weed control. The final 2007 weed count revealed less broadleaf weeds in the rotary hoe + Danish tined weeder treatment (6 plants per yard^2) compared to the rotary hoe + Lilliston cultivator (10 plants per yard^2). In 2007, populations were recorded after all field operations were complete and revealed no differences among the implements.

Flaming and rotary hoeing in corn

Creston, IA

Grower question: ***After rotary hoeing once prior to corn emergence, how does flaming compare with a second rotary hoeing?***

Methods

In this two year study, corn was planted in 36-inch rows on May 13, 2006 and May 17, 2007 at populations of 30,000 plants per acre in Creston, IA. Each year the entire field was rotary hoed once and in 2007 everything was harrowed. Following that two weed control treatments were compared: rotary hoeing once more and flaming. After the 2 rotary hoe passes and prior to flaming all plots were uniformly cultivated (2006 required a second cultivation pass after flaming). Each treatment had 6 replications. Counts of broadleaf weeds, greater than 6 inches in height, and grass ratings were taken in August of each year. Operating costs were recorded throughout the season.

Figure 30. Four-row propane flamer.

Table 3. Planting and weed management dates.							
Year	Planting	Harrow drag	Rotary hoe (1st pass)	Rotary hoe (2nd pass)	Cultivator (1st pass)	LP flamer	Cultivator (2nd pass)
2006	May 13	NAB	May 22	June 1	June 7	June 15	June 24
2007	May 7	May 23	May 28	June 7	June 13	June 21	NA

Results

No significant differences in weed populations, corn stand or corn yield were observed among the rotary hoeing and the flaming treatments for either year. In 2007, the plots had very few weeds when flamed, therefore flaming was not cost effective. In both years the rotary hoe only treatment was the least costly at $29.90 and $25.50 per acre in 2006 and 2007, respectively, while the rotary hoe + flamer treatments were $33.20 and $27.50 per acre in 2006 and 2007, respectively. Overall, costs in 2007 were cheaper than 2006 because cultivation was only needed once and hand labor was not needed.

Figure 31. Pigweed before (left) and after (right) flaming in 2006.

Figure 32. There was little weed pressure in the rotary hoe + flame (left) and rotary hoe only (right) treatments prior to flaming in 2007.

Flaming and rotary hoeing in soybean

Alma, MI

Grower question: ***What is the most cost effective means of controlling weeds in soybean (i.e. rotary hoeing alone, rotary hoeing & flaming, flaming alone)?***

Methods

A two year study in Alma, MI compared the effectiveness of controlling in-row weeds in soybean using a propane flamer (F), a rotary hoe (RH), and a combination of the two (RHF). Within the field there were two one acre strips for each treatment (i.e. RH, RHF, and F). See Table 3 in Chapter 4 for weed management timings.

In 2006, the flaming treatment ended up being rotary hoed one time to promote soybean emergence. During the season observations regarding weed control were made and information relating to the expenses and time input of the weed management practices were recorded. The flaming only treatment was the least expensive (Table 3, page 68).

Figure 33. Size of common ragweed (left) and common lambsquaters (right) at the time of flaming in both 2006 and 2007.

Figure 34. Soybeans immediately after flaming in 2006 (left) and 2007 (right).

Results

In 2006, soybean cotyledons were scalded from the flamer, but quickly outgrew the damage. Giant foxtail was more prevalent in plots that were not flamed (i.e. rotary hoeing alone). There were no noticeable differences in broadleaf weeds among treatments. Due to the high populations of giant foxtail, hand weeding took longer in the rotary hoeing alone treatment. The flaming only treatment was the least expensive ($45.97 per acre), followed by the rotary hoe + flaming ($47.75 per acre), and lastly rotary hoeing alone ($54.45 per acre). In 2007, the soybeans were flamed preemergence due to weather constraints. There were no differences in weed populations, which could be due to low overall weed pressure. The rotary hoeing only treatment was the least expensive ($34.93 per acre), followed by the rotary hoe + flaming treatment ($42.42 per acre) and the flame only treatment ($53.56 per acre). Over the two years the most consistent treatment for costs and weed control was the rotary hoe + flaming treatment.

Organic herbicide for weed control in soybean

West Bend, WI

Grower question: ***Can a molasses and calcium based organic herbicide in combination with a rotary hoe help control weeds?***

Methods

Some believe cane molasses and soluble calcium offer some weed suppression. To examine this claim, seven acres were planted to soybean in West Bend, WI on June 14, 2007 at 178,000 seeds per acre in 30-inch rows. The experimental treatments included 1) no herbicide, no rotary hoe, 2) herbicide, no rotary hoe, 3) no herbicide, rotary hoe, and 4) herbicide, rotary hoe. Each treatment was replicated four times. The organic (i.e. non-synthetic) herbicide was applied to treatments 2 and 4 at 20 gallons per acre (see formulation on right). Treatments 3 and 4 were rotary hoed once four days after planting. After the experimental treatments were complete all plots were uniformly cultivated on July 20 and August 4. Weed counts were taken in 30 foot sections of row for each plot at one week after planting (WAP), two WAP, and eight WAP. Yields were recorded at harvest.

Results

Velvetleaf, common ragweed, Canada thistle, and quackgrass were the prominent weeds across the field. There were no significant differences in broadleaf or grass weed populations among the four treatments at any of the three sampling dates. Eight WAP there were averages of 3 broadleaves per yard^2 and 2 grasses per yard^2. Also, there were no differences in yield across the field, with an average yield of 49 bushels per acre.

Non-synthetic herbicide formula

- 3 gallons cane molasses (79 Brix)
- 1.37 gallons AgriEnergy Resources Mineral Max
- 1 gallon Drammatic "L" Fish Hydrolysate
- 1 gallon AgriEnergy Resources Algae Concentrate
- 1 gallon AgriEnergy Resources SP-1
- 1/2 gallon AgriEnergy Resources 6% Organic Calcium (derived from limestone)
- 1 gallon AgriEnergy Resources Bio-Humus
- Water

Figure 35. Soybeans were planted into freshly incorporated oats (top) and immediately sprayed with the molasses + calcium mix (bottom).

Figure 36. Soybean field that had rotary hoeing and organic herbicide application, July 14.

Figure 37. Soybean field that had rotary hoeing and no organic herbicide application, July 14.

Figure 38. Soybean field that had rotary hoeing and organic herbicide application, August 4.

Figure 39. Soybean field that had rotary hoeing and no organic herbicide application, August 4.

Figure 40. Soybean field that had rotary hoeing and organic herbicide application, November 5.

Figure 41. Soybean field that had rotary hoeing and no organic herbicide application, November 5.

Appendix A.

The Second Dirty Dozen (Plus Two): – Profiles for Common Michigan Weeds

Authors: Christy Sprague and Erin Taylor

Summer annuals

- **Fall panicum**
- **Jimsonweed**

Winter annual/Summer annual

- **Wild mustard**

Winter annuals

- **Henbit**
- **Purple deadnettle**

Biennials

- **White campion (white cockle)**
- **Wild carrot**

Perennials

- **Canada thistle**
- **Common pokeweed**
- **Curly dock**
- **Horsenettle**
- **Perennial sowthistle**
- **Quackgrass**
- **Yellow nutsedge**

Summer annuals

Fall panicum

(***Panicum dichotomiflorum***)

Life cycle: summer annual. Emerges in late spring, flowers from July to October and dies with frost. A later emerger, 10% emergence occurs after 350 GDD (base 48° F).

Depth of weed emergence: primarily emerges from soil depths of 1/2 to 1 inch. However, emergence can occur from 3-inch soil depths.

Weed reproduction: reproduces by seed, produces 500,000 seeds per plant.

Special dispersal mechanisms: none.

Weed seed longevity: highly persistent seed. Seed germination was high after 10 years of burial. It was predicted that it would take 313 years to reduce germination to 1%.

Weed seed dormancy: initially dormant. After-ripening is required for seed germination.

Competitiveness: moderately competitive. Eight plants per yard of row reduced soybean yield 15%.

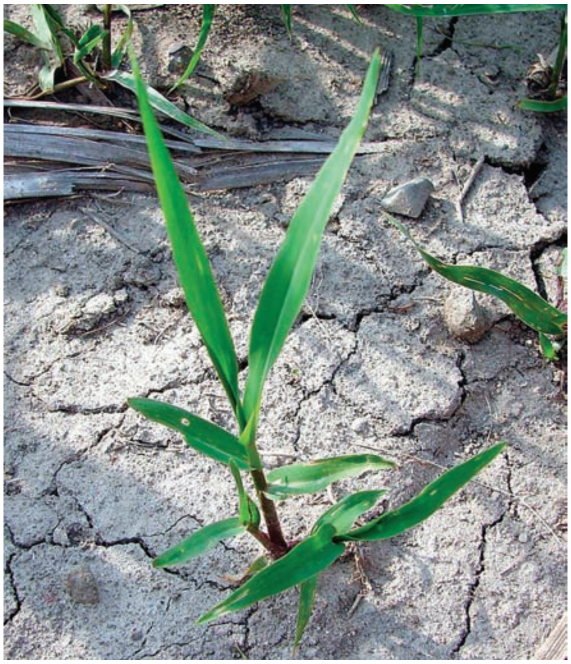
Preferred soil/field conditions: found on most soil types.

Management practices

Biological

Predation/grazing – not highly palatable to grazing animals. Ground beetles (carabids) eat fall panicum seed that is lying on the soil surface.

Decay – no information.



Christy Sprague

Mechanical

Tillage – seedlings are readily controlled by tillage.

Rotary hoeing – more difficult to control than small broadleaf weeds. Hoe before fall panicum exceed 1/4 inch in height.

Flaming – grasses are more difficult to control with flaming.

Cultural

Crop rotation – seldom a weed of small grains and forages.

Planting date – earlier planting may improve crop canopy development to help suppress fall panicum infestations.

Chemical

Application timing and effectiveness – fall panicum is easily controlled in broadleaf crops. Controlling emerged fall panicum in corn is more difficult. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Steven Gower

Christy Sprague

Jimsonweed

(*Datura stramonium*)

Life cycle: summer annual. Jimsonweed emerges in spring (May through mid-June), sets seed in late summer/fall and dies with the first killing frost.

Depth of weed emergence: emerges from soil depths of 3 inches or less.

Weed reproduction: reproduces by seed. Without competition one jimsonweed plant can produce 50 or more seed capsules and 30,000 or more seeds. Each seed capsule generally contains 600 to 700 seeds. Under severe competition one plant may only produce 3 to 4 small seed capsules. Seed capsules are produced until the first hard frost.

Special dispersal mechanisms: seed capsules and seed are buoyant in water and can remaining floating for 10 days or more. Seeds are dispersed by dehiscence (splitting open of the seed capsule) up to a distance of 3 to 10 feet from the parent plant. Jimsonweed can also be dispersed by farm machinery, water and impurities in commercial seed.

Weed seed longevity: moderate to highly persistent. Ninety-one percent of seeds germinated after 39 years in a buried seed experiment.

Weed seed dormancy: very little dormancy of mature seeds. Seeds are mature 30 day after fertilization, capsule opens 50 days after pollination and seeds will continue to ripen after fertilization even if the branch where the seed capsule is located is not attached to the plant.

Competitiveness: one of the more competitive weeds. Four to 13 plants per yard^2 can reduce yields of direct-seeded tomatoes by 26 to 71% and soybeans by 15 to 45%. Jimsonweed also interferes with harvesting operations.

Preferred soil/field conditions: found on most soil types, but prefers rich soils, including disturbed soils rich in manure (i.e., barnyards).

Management practices

Biological

Predation/grazing – jimsonweed vegetation and seeds are poisonous due to production of tropane alkaloids. Livestock normally avoid eating jimsonweed unless no other vegetation is available.

Erin Taylor

Decay – seeds decay more readily on the soil surface.

Mechanical

Tillage – seedlings are readily killed by tillage. However, older plants may regenerate from lower nodes that are clipped or trampled.

Rotary hoeing – hoe before weeds exceed 1/4 inch in height. Once jimsonweed is established it is difficult to control.

Flaming – effective on small jimsonweed.

Cultural

Crop rotation – not a weed of small grains or forages.

Planting date – tillage in the spring triggers jimsonweed to germinate. Because of the extended time of emergence, planting early or planting late to reduce jimsonweed infestations may not be effective.

Erin Taylor

Chemical

Application timing and effectiveness – several herbicides are effective in corn, soybean, dry bean and sugar beets. Control is greater when herbicides are applied to smaller jimsonweed plants. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Jimsonweed can serve as an alternate host of many insect pests and diseases of *Solanaceous* crops, such as tomatoes and potatoes.

Erin Taylor

Winter/Summer annuals

Wild mustard

(*Brassica kaber*)

Life cycle: winter/summer annual. Emerges in late summer, early fall or spring. In Michigan, several populations of wild mustard act as summer annuals. Flowering peaks in June and July, but can continue until the first frost.

Depth of weed emergence: emerges from soil depths of 1 inch or less.

Weed reproduction: reproduces by seed, produces approximately 1,200 seeds per plant.

Special dispersal mechanisms: seed pod dehiscence (splitting open).

Weed seed longevity: low persistence – 50% of the seed bank is reduced in less than one year, and it takes 7 years to reduce the seed bank 99%.

Weed seed dormancy: initially dormant. Dormancy is broken by a combination of changes in temperature, light and nitrate levels.

Competitiveness: one of the more competitive weeds with small grains, soybean and corn. Winter cereal yields were reduced 13 to 69% when the biomass was comprised of 1 to 60% wild mustard. Soybean yields were reduced 46% with 4 plants per yard of row and corn yields were reduced 1.5- to 2-fold and 5- to 6-fold at low and high wild mustard densities, respectively.

Preferred soil/field conditions: grows on a wide range of soils.

Management practices

Biological

Predation/grazing – ground beetles (carabids) eat wild mustard seed lying on the soil surface.

Erin Taylor

Decay – no information.

Mechanical

Tillage – seedlings are readily killed by tillage

Rotary hoeing – hoe before weeds exceed $^1/_4$ inch in height, once established wild mustard is difficult to control.

Erin Taylor

Flaming – effective on small wild mustard.

Cultural

Crop rotation – corn-soybean rotations will deplete wild mustard populations more rapidly than continuous wheat.

Planting date – later planting will reduce wild mustard populations.

Chemical

Application timing and effectiveness – several herbicides are effective for controlling wild mustard. Control is greater when herbicides are applied to smaller wild mustard plants. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Wild mustard can serve as an alternate host of nematodes and many insect pests.

Erin Taylor

Winter annuals

Henbit

(***Lamium amplexicaule***)

Life cycle: winter annual: Emerges mostly in the fall, but can have some emergence in early spring, flowering and seed set begins in early spring. Plants die with hot, dry weather in late-May and June.

Depth of weed emergence: primarily emerges from soil depth of 1 inch or less. However, emergence can occur from 2 $\frac{1}{2}$-inch soil depths.

Weed reproduction: reproduces by seed, produces more than 2,000 seeds per plant.

Special dispersal mechanisms: none.

Weed seed longevity: moderate persistence – seeds can remain viable for 25 to 40 years.

Weed seed dormancy: initially dormant, high summer temperatures after ripen seed to break dormancy.

Competitiveness: not very competitive. Twenty-one henbit plants per yard^2 did not reduce wheat yields. At 98 and 184 plants per yard^2 winter wheat yields were reduced 13 and 38%, respectively.

Preferred soil/field conditions: thrives in rich fertile soils, however, will also grow in light sandy soils.

Management practices

Biological

Predation/grazing – not preferred by grazing animals. Under high infestations henbit has caused some minor neurological problems in sheep, cattle and horses.

Decay – no information.

Mechanical

Tillage – tillage in early fall during the daytime can increase henbit germination. However, henbit seedlings are readily controlled by late-fall and early-spring tillage.

Rotary hoeing – primarily a no-till weed, not likely present at time of hoeing.

Flaming – no information.

Cultural

Crop rotation – typically a problem of small grains, alfalfa and no-tillage systems. Planting small grains at higher populations will suppress henbit.

Planting date – tillage in the spring and planting later (mid-May) will reduce henbit infestations.

Erin Taylor

Chemical

Application timing and effectiveness – easily controlled with herbicides. Fall and early spring herbicide applications are generally most effective and may also suppress seed production. Keep in mind that there may be some spring emergence, so consider using a residual herbicide. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Henbit can serve as an alternate host for soybean cyst nematode, two-spotted spider mites and tomato spotted wilt.

Erin Taylor

Aaron Hagar

Purple deadnettle

(*Lamium purpureum*)

Life cycle: winter annual. Primarily emerges in the fall, flowering and seed set begins in early spring. Plants die with hot, dry weather in late-May and June.

Depth of weed emergence: primarily emerges from soil depth of 1 inch or less. However, emergence can occur from 2 $^{1}/_{2}$-inch soil depths.

Weed reproduction: reproduces by seed, produces 27,000 seeds per plant without competition.

Special dispersal mechanisms: none.

Weed seed longevity: moderate to very long persistence—about 20% of seed was lost from the soil seed bank each year in a 6-year experiment. However, there have been reports of purple deadnettle seed still viable after 660 years.

Weed seed dormancy: initially dormant, high summer temperatures break dormancy and seed germinated in the fall.

Competitiveness: not very competitive with small grains.

Preferred soil/field conditions: thrives in nutrient-rich and mildly humic, loamy or sandy-loam soils.

Management practices

Biological

Predation/grazing – no information.

Decay – no information.

Mechanical

Tillage – purple deadnettle is readily controlled by tillage in the late-fall or early spring.

Rotary hoeing – primarily a no-till weed, not likely present at time of hoeing.

Flaming – no information.

Cultural

Crop rotation – typically a problem of small grains, alfalfa and no-tillage systems. Planting small grains at higher populations will suppress purple deadnettle.

Planting date – tillage in the spring and planting later (mid-May) will reduce purple deadnettle infestations.

Chemical

Application timing and effectiveness – easily controlled with herbicides. Fall and early spring herbicide applications are generally most effective and may also suppress seed production. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Purple deadnettle can serve as an alternate host for soybean cyst nematode.

Biennials

White campion (white cockle)

(*Silene alba*)

Life cycle: biennial or short-lived perennial. Seeds germinate primarily in the fall, but seedlings can also emerge in late spring. Plants initially form a rosette and subsequently produce erect leafy stems with flowers. Plants overwinter as a rosette. Seedlings and flowering plants are often found together in the spring.

Depth of weed emergence: emerges from soil depths of 1 inch or less.

Weed reproduction: reproduces primarily by seed. New plants can also be formed from adventitious buds on crown-roots segments. Averages 367 seeds per capsule and 66 capsules per plant, total average seed production is 24,000 seeds per plant.

Special dispersal mechanisms: none.

Weed seed longevity: no information.

Weed seed dormancy: short period of dormancy after seed dispersal, 11 to 48% of seed germinated after 1 month.

Competitiveness: moderately competitive, dependent on white campion populations.

Preferred soil/field conditions: rich, well-drained soils. White campion does not tolerate wet soils.

Management practices

Biological

Predation/grazing – none.

Decay – none.

Mechanical

Tillage – not a huge problem in tilled systems. Tillage reduces white cockle infestations by 98%. However, tillage can move root crown segments, which can produce new plants. Deep burial or drying on soil surface cause very little regenerations from roots.

Rotary hoeing – not effective.

Flaming – no information.

Mowing – frequent mowing or cutting will reduce white campion infestations.

Cultural

Crop rotation – mostly a problem in rotations that have little soil disturbance (no-till and perennial crops).

Planting date – most likely will not affect white campion infestations.

Erin Taylor

Chemical

Application timing and effectiveness – fall herbicide applications are more effective than spring applications. Spring herbicide applications should be made prior to bolting and flowering. White campion is tolerant of 2,4-D products, so other herbicides like glyphosate should be used for control. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

White campion can serve as an alternate host for viruses that can infect sugar beet and spinach.

Erin Taylor

Wild carrot

(***Daucus carota***)

Life cycle: biennial or short-lived perennial. Emerges primarily in spring, but also in summer and fall. Forms a basal rosette of leaves the first year and an erect flowering stalk the following year, flowering occurs from July to September. Plants die after flowering. Some plants may act as an annual and flower in the first year.

Depth of weed emergence: most seeds germinate from 1/4-inch soil depth, however wild carrot can germinate from depths of 4 inches.

Weed reproduction: reproduces by seed. One plant can produce between 1,000 and 40,000 seeds.

Special dispersal mechanisms: when seeds are mature the dry umbel (flower) flexes outward releasing seed, the umbel then closes under damp conditions. The cycle is repeated. Some seed will be dispersed short distances by wind or longer distances by animals (hooked spines of seed attach to fur).

Weed seed longevity: seeds can remain dormant in the soil for several years.

Weed seed dormancy: initially dormant, by 6 months 20% of wild carrot seed germinates.

Competitiveness: moderately competitive, dependent on wild carrot populations.

Preferred soil/field conditions: grows on well-drained to dry soils, with low to moderate soil fertility.

Management practices

Biological

Predation/grazing – sheep, horses and cattle will graze on wild carrot. Dairy cow consumption of wild carrot in large quantities will taint milk. Lygus plant bug species nymphs can destroy the embryos of wild carrot seed. Wild carrot roots can be attacked by maggots of carrot rust fly, lesion nematodes and root knot nematodes.

Decay – no information.

Aaron Hagar

Erin Taylor

Mechanical

Tillage – uprooting, chopping, and then burying the taproots will control wild carrot (that is why wild carrot is not a problem in tilled cropping systems).

Rotary hoeing – not effective.

Flaming – no information.

Mowing – susceptible to mowing or clipping at the flowering stage. Frequent mowing reduces wild carrot size and seed production. A single clipping in July has been shown to stop seed production.

Cultural

Crop rotation – mostly a problem in rotations that have little soil disturbance (no-till and perennial crops).

Planting date – most likely will not affect wild carrot infestations.

Chemical

Application timing and effectiveness – spring applications of labeled herbicides are effective in controlling seedling wild carrot. However, once wild carrot becomes established fall herbicide applications are more effective. Sequential herbicide applications may be necessary for control. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Wild carrot can serve as an alternate host for aster yellows, which can cause losses in cultivated carrot crops.

Perennials

Canada thistle

(***Cirsium arvense***)

Life cycle: perennial. Emerges in spring and flowers when days are the longest. Plants die after the first killing frost.

Depth of weed emergence: seedlings produced from seeds emerge from soil depths of $^1/_4$- to $^1/_2$-inch. However, seeds have been found to germinate from 3-inch soil depths. Adventitious shoots (vegetative propagules) from creeping roots can come up from greater depths.

Weed reproduction: most local reproduction is from creeping roots. Seed production allows for local and long distance reproduction. Seed production ranges from 1,500 to 5,300 seeds per plant.

Special dispersal mechanisms: creeping roots can be moved from field to field on tillage equipment. Each seed has an attached pappus which allows for wind dispersal.

Weed seed longevity: low to moderate persistence—when buried 1 to 3 inches in the soil 45 to 60% of seed germinates the first year and less than 1% survives after 3 to 5 years. When buried at greater depths (7 inches or more) and left undisturbed, seeds have been found to be viable for up to 30 years.

Weed seed dormancy: though most seed is capable of germinating upon dispersal in the fall, it enters secondary dormancy during the winter months.

Competitiveness: moderate shoot densities have been shown to reduce spring wheat yield and alfalfa seed yield by up to 50%.

Preferred soil/field conditions: prefers perennial and no-till cropping systems and rangelands.

Management practices

Biological

Predation/grazing – when present, *Orellia ruficauda* (i.e. a seed-head fly found in Canada and the United States) can be responsible for 20 to 80% seed predation. Other agents have been studied, but eliminated for various reasons. Some livestock have been known to graze on Canada thistle at different life stages (see Chapter 5).

Decay – no information.

Mechanical

Tillage – tillage, mowing and other forms of mechanical control have been deemed ineffective for control. Tillage can increase the problem by spreading vegetative propagules.

Rotary hoeing – not effective.

Flaming – not effective.

Erin Taylor

Cultural

Crop rotation – Canada thistle populations have been shown to be reduced by the use of a summer annual cover crop such as sudangrass (see cover crops chapter).

Planting date – most likely will not affect Canada thistle infestations.

Chemical

Application timing and effectiveness – most susceptible to herbicides between the bud and flower stages of Canada thistle. Sequential herbicide applications may be necessary for control. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Erin Taylor

Erin Taylor

Common pokeweed

(***Phytolacca americana***)

Life cycle: perennial. Emerges in the spring and flowers from summer through fall. Berries turn black at maturity. Stems and leaves die back in the winter.

Depth of weed emergence: very little germination occurs 1 $^1/_2$ inches below the soil surface.

Weed reproduction: reproduces by seed. Plants resprout from taproots.

Special dispersal mechanisms: birds eat pokeweed berries, the seeds survive digestion, and are redeposited to create new infestations.

Weed seed longevity: pokeweed seeds can remain viable in the seed bank for up to 40 years.

Weed seed dormancy: some seed can germinate immediately after dispersal if exposed to light, however over-wintering (i.e. stratification) increases the germination speed and the number of seeds that will germinate. Over-wintering is required for seed to germinate in the dark.

Competitiveness: very competitive with field crops in reduced and no-till systems.

Preferred soil/field conditions: prefers areas of reduced tillage.

Management practices

Biological

Predation/grazing – no information.

Decay – no information.

Mechanical

Tillage – this weed is effectively controlled by tillage, such as moldboard plowing and disking.

Rotary hoeing – not effective.

Flaming – no information.

Erin Taylor

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Cultural

Crop rotation – rotations that include tillable row crops can help reduce pokeweed.

Planting date – most likely will not affect common pokeweed infestations.

Chemical

Application timing and effectiveness – seedlings are readily controlled by residual herbicides. Established plants are most susceptible to herbicides when they are between 8- and 12-inches tall. Sequential herbicide applications may be necessary for control. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Additional information

Common pokeweed can be an alternate host for soybean cyst nematode.

Aaron Hagar

Curly dock

(*Rumex crispus*)

Life cycle: simple perennial. Seeds germinate from late spring through early fall producing seedlings. Perennial plants emerge in mid-spring from taproots, producing a robust rosette. Flowering occurs primarily in June.

Depth of weed emergence: emerges from soil depths of 3 inches or less.

Weed reproduction: reproduces by seed, production can range from 100 to more than 60,000 seeds per plant. Plants resprout from taproots.

Special dispersal mechanisms: the membranous wings of the fruit are readily dispersed by wind and water.

Weed seed longevity: moderately persistence—the seed bank was reduced 50% after 3 years, and it took 17 years to reduce the curly dock seed bank 99%.

Weed seed dormancy: no information.

Competitiveness: moderately competitive.

Preferred soil/field conditions: thrives in nutrient rich, heavy damp soils, but can adapt to dry areas with poor soils. Curly dock does not tolerate acidic soils.

Erin Taylor

Management practices

Biological

Predation/grazing – not readily eaten by livestock, intensive grazing will likely result in an increase in curly dock populations.

Decay – no information.

Mechanical

Tillage – uprooting, chopping and then burying the taproots will control curly dock (that is why curly dock is not a problem in tilled cropping systems). Using a shovel to remove the crown about 2 inches below the soil surface is also effective.

Rotary hoeing – not effective.

Flaming – not effective.

Mowing – mowing will prevent seed production and reduce top growth.

Cultural

Crop rotation – mostly a problem in rotations that have little soil disturbance (no-till and perennial crops).

Planting date – most likely will not affect curly dock infestations.

Chemical

Application timing and effectiveness – spring applications of labeled herbicides are effective in controlling seedling curly dock. However, once curly dock becomes established fall herbicide applications are more effective. Sequential herbicide applications may be necessary for control.

Additional information

Considered a noxious weed of Michigan, Indiana, Iowa and Minnesota.

Erin Taylor

Horsenettle

(***Solanum carolinense***)

Life cycle: perennial. Flowers bloom in late-spring to early summer, forming yellow berries containing seeds that shrivel in the fall. The aboveground plant tissue dies back after a frost.

Depth of weed emergence: seeds germinate well within 1 inch of the soil surface. Very few plants emerge from seeds at depths of 4 inches or greater. Two-thirds of roots (6-inches long) buried 18 inches below the soil surface can produce new shoots; emergence decreases at greater depths.

Weed reproduction: reproduces by seed and vegetative reproduction of new shoots from creeping roots.

Special dispersal mechanisms: the berries, with seeds inside, are eaten by animals and then deposited. Berries that are not eaten drop to the ground.

Weed seed longevity: under laboratory conditions seeds remain viable for at least 7 years.

Weed seed dormancy: some of the seeds of horsenettle are dormant at the time of dispersal in the fall. This dormancy is broken by the following spring.

Competitiveness: Horsenettle established for one year prior to planting snapbeans reduced yields by 18 to 20%. As the length of establishment increased so did yield reduction, with yield reductions of 48 to 65% in snapbeans competing with three-year-old horsenettle plants. Horsenettle has also been shown to reduce yields in peanut by up to 40%. In addition to being a good competitor with crops, horsenettle is poisonous to livestock.

Preferred soil/field conditions: can grow in a variety of soil types, though it prefers a sandy or gravelly textured substrate.

Management practices

Biological

Predation/grazing – no information.

Decay – no information.

Aaron Hagar

Mechanical

Tillage – tillage at any depth can increase the spread of horsenettle.

Rotary hoeing – no information.

Flaming – no information.

Mowing – mowing early in the season encourages horsenettle growth; mowing later in the season decreases growth.

Cultural

Crop rotation – no information.

Planting date – most likely will not affect horsenettle infestations.

Chemical

Application timing and effectiveness – very few herbicides are effective at controlling horsenettle. Sequential herbicide applications are necessary for control.

Aaron Hagar

Perennial sowthistle

(*Sonchus arvensis*)

Life cycle: perennial. Emerges in the spring, flowers throughout the summer and sets seed in the fall. Aboveground plant tissue dies after the first frost.

Depth of weed emergence: germination is reduced at depths greater than $1/4$ inch, with no seeds germinating from depths greater than 1 $1/4$ inches.

Weed reproduction: reproduces by seed and the vegetative buds of roots.

Special dispersal mechanisms: each seed has an attached pappus which allows for wind dispersal. Hooked cells on the pappus hairs can also cling to fur or clothing to help disperse seed.

Weed seed longevity: though longevity is largely dependent on environmental conditions, seed viability has been shown to be reduced by up to 90% three years after dispersal.

Weed seed dormancy: little to no seed dormancy.

Competitiveness: densities of 17 and 32 shoots per yards^2 reduced wheat yield by 15 and 45%, respectively. High densities (more than 83 plants per yard^2) have been shown to reduce soybean and dry bean yields by 49 and 36%, respectively. In dry years these effects are exacerbated resulting in over 80% reductions in the yields of both crops.

Preferred soil/field conditions: grows in a variety of soil types with slightly alkaline to neutral pH, preferring fine to slightly-course soils rich in nutrients.

Management practices

Biological

Predation/grazing – due to the palatability of this weed, grazing cattle and sheep help reduce populations.

Decay – no information.

Mechanical

Tillage – tillage at the 7 to 9 leaf rosette stage reduces the reproductive capacity of root systems. Burial of plants 12 inches deep reduced new shoot emergence by 90%.

Rotary hoeing – not effective.

Erin Taylor

Flaming – not effective.

Cultural

Crop rotation – in South Dakota drilling crops such as soybeans, sudangrass, buckwheat and forage sorghum after three tillage passes reduced perennial sowthistle populations by 70 to 80%. A complete year of fallow, which includes spring plowing and cultivating every 2 to 4 weeks, can reduce perennial sowthistle densities by 99%.

Planting date – most likely will not affect perennial sowthistle infestations.

Chemical

Application timing and effectiveness – most susceptible to herbicides in the fall at the rosette stage or between the bud and flower stages. Sequential herbicide applications may be necessary for control.

Erin Taylor

Quackgrass

(*Elytrigia repens*)

Life cycle: perennial. Emerges in the spring, flowers in early summer, and sets seed in late summer. Plants remain green all year.

Depth of weed emergence: seeds germinate well within 2 inches of the soil surface. Very few plants emerge from seeds at depths of 4 inches or greater. Rhizomes are capable of producing shoots from 6 inches below the surface, but are more likely to produce shoots when buried only 1 to 2 inches.

Weed reproduction: reproduces by seed and the spread of rhizomes.

Special dispersal mechanisms: local populations are established from the spread of rhizomes. Seeds will not germinate in areas of established quackgrass.

Weed seed longevity: seed quickly looses all viability in 2 to 4 years.

Weed seed dormancy: seed does not enter dormancy. Up to 90% of fresh seed will germinate when exposed to fluctuating temperatures. Viability declines rapidly after initial dispersal.

Competitiveness: high levels of infestation can result in up to 85% yield loss in potato. Very high densities (893 shoots/yard^2) have also been shown to reduce corn yields by 37%.

Preferred soil/field conditions: prefers areas of reduced tillage and fertile areas where tillage occurs.

Management practices

Biological

Predation/grazing – some work has been done with domesticated geese, which preferentially feed on quackgrass. Quackgrass is susceptible to pollen allelopathy from Timothy (*Phleum pretense*), which reduces seed production and over time can reduce local populations.

Decay – no information.

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Mechanical

Tillage – quackgrass is poorly controlled by mechanical means unless repeatedly cultivated or plowed each time it begins to re-grow. Often, fragmented rhizomes can worsen the infestation locally and can spread quackgrass to other fields with rhizomes stuck on equipment.

Rotary hoeing – not effective.

Flaming – not effective.

Cultural

Crop rotation – highly competitive fall planted cover crops (e.g. hairy vetch) and spring planted cover crops that quickly accrue biomass (e.g. buckwheat) have been shown to drastically reduce quackgrass populations.

Planting date – most likely will not affect quackgrass infestations.

Chemical

Application timing and effectiveness – several herbicides are labeled for control of quackgrass. Herbicides that can be applied postemergence and that are systemic are the most effective. Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).

Steven Gower

Yellow nutsedge

(*Cyperus esculentus*)

Life cycle: perennial. Emerges in the spring, flowers in the summer, and sets seed late-summer to fall. Aboveground material and rhizomes die after a killing frost; tubers survive through the winter.

Depth of weed emergence: tubers can produce shoots from as deep as 31 1/2 inches below the soil surface.

Weed reproduction: reproduction primarily occurs by tubers (i.e. nutlets). Some reproduction takes place via seeds, though viability is low.

Special dispersal mechanisms: none.

Weed seed/tuber longevity: at a depth of 2 inches, seed viability decreases by 90% in less than 2 years. Tubers can remain viable for up to 3 1/2 years in the soil.

Weed seed dormancy: tubers are mostly dormant during the season they are formed. After exposure to cold temperatures and leaching, most of this initial dormancy is broken when temperatures warm the following spring.

Competitiveness: corn yield is reduced by 8% for every 119 shoots per yard^2.

Preferred soil/field conditions: grows on a variety of soil types and moisture levels, often starting in wet areas and spreading.

Management practices

Biological

Predation/grazing – no information.

Decay – no information.

Other – an indigenous rust (*Puccinia canaliculata*) was found to successfully control yellow nutsedge, though production problems have stood in the way of commercial use.

Mechanical

Tillage – tillage every three weeks throughout the season can reduce viability by 80% because tubers are exposed to prolonged drying on the soil surface. Intensive tillage in a three year corn-cotton-peanut rotation reduced yellow nutsedge tubers by 97 to 99% (hand weeding was also done in the cotton).

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Rotary hoeing – rotary hoeing was a part of the intensive tillage system in the corn-cotton-peanut rotation mentioned above that drastically reduced the number of nutsedge tubers.

Flaming – not effective.

Cultural

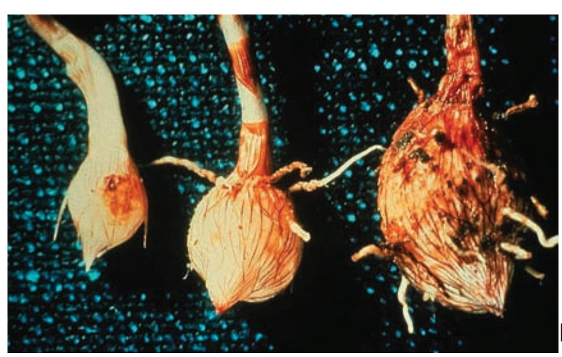
Crop rotation – summer fallow allowing for multiple tillage passes and/or herbicide applications is one strategy for nutsedge control.

Planting date – differences in corn planting dates do not effect yellow nutsedge biomass or tuber production.

Other – keeping cultivation and tillage equipment clean will prevent spread to other fields.

Chemical

Application timing and effectiveness – several herbicides are labeled for control of nutsedge. Most effective herbicides are usually applied preplant incorporated (PPI) or postemergence (POST). Please refer to E-0434, "MSU Weed Control Guide for Field Crops," for herbicide recommendations (www.msuweeds.com/publications).



Steven Gower

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