Protecting Wisconsin's Resources through Integrated Weed Management

About this publication

Increasing growers' knowledge of cultural and mechanical farming practices as they relate to weed management should be a goal for all agricultural educators. Enhancing crop competition against weeds by proper planting date, seeding rate and row spacing are just a few of the important practices that can be reinforced through education. These topics and others are presented in this publication to provide a foundation of knowledge from which integrated weed management systems can be built.

While the information presented in this publication is presented in discrete chapters, it is hoped that users of this publication will see how these practices fit together into an integrated system. This publication is neither pro- nor anti-chemical. Instead it tries to provide a balanced approach to weed management, realizing that herbicides are but one tool in the weed management toolbox. The authors hope that the concepts provided in this publication will start a thinking process that includes all the building blocks of an integrated weed management system.

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Herbicides, Regulations and Water Quality:
The Status in Wisconsin

Countless research studies have found herbicides in surface water and groundwater. In some instances, the herbicide contamination is known to come from spills or accidents; in others it has been shown to come from routine applications to fields at normal label rates. If herbicides are used, there is no known way to completely ensure that they will not reach a water resource after field application. The only way to totally eliminate the possibility of water contamination is to stop the use of herbicides. Many farmers will agree, however, that herbicides are a necessary tool for the control of weeds and that their use should not be prohibited.

This chapter does not take either side of the issue of whether or not herbicides should be used. It describes herbicide findings in Wisconsin groundwater and the steps the state of Wisconsin is taking to remedy and prevent further environmental problems caused by herbicides. Its purpose is to inform persons making weed control decisions and provide some perspective on the environmental consequences of using herbicides.

Federal and state pesticide regulations

Pesticide use in Wisconsin is governed by both federal and state pesticide regulations. This section provides a brief overview of laws regulating pesticide use in Wisconsin. It is by no means complete, and the reader should consult the actual laws and regulations to answer compliance questions.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Today's Federal pesticide regulation is called the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The initial Federal pesticide law (Insecticide Act of 1910) was designed to protect farmers from adulterated or misbranded products. Congress later broadened FIFRA by adding amendments that required all pesticides to be registered prior to interstate sale. Later amendments allowed registration refusal for pesticides that were unsafe or ineffective and removed them from the market. The 1972 amendments to FIFRA shifted away from efficacy issues towards greater emphasis on minimizing health risks and environmental degradation from pesticide toxicity.

Under FIFRA, no one may sell, distribute, or use a pesticide unless it is registered by the U.S. Environmental Protection Agency (EPA). EPA will only register a product if the test data, submitted by the manufacturer, meet all the necessary criteria. EPA must also reregister all pesticide active ingredients registered prior to November 1984 to assure they conform to current standards. The manufacturer must also submit a label that states specific information on how to properly use the pesticide. An important provision of FIFRA makes it illegal to use a pesticide "in a manner inconsistent with its labeling." In other words, the label is the law. FIFRA is constantly being revised to address new concerns and technologies and to continue to protect the public, environment and farming.

Under FIFRA, the pesticide label is the law.

Wisconsin Pesticide Law and Administrative Rule, Chapter ATCP 29

In addition to the federal pesticide laws, Wisconsin also regulates pesticides through the Wisconsin Pesticide Law and Administrative Rule, Chapter ATCP 29. The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) has primary responsibility for pesticide use and control in the state. The Wisconsin Department of Natural Resources (DNR) has responsibility for pesticide use involving the "waters of the state." Preparing communities to respond to the accidental release of hazardous compounds, including pesticides, is the responsibility of the Wisconsin Division of Emergency Governments.

Pesticide applicator certification requirements

Ultimately, the safe handling and use of pesticides is the obligation of the user. In recognition of this, FIFRA requires each state to develop and implement a training and certification program for both private and commercial pesticide applicators. Private pesticide applicators need to be certified if purchasing and using restricted-use pesticides. (A restricted-use pesticide is one that may result in unreasonable adverse effects on human health and/or the environment if used by untrained persons, but its use by a trained person would prevent this effect.) All commercial applicators must be certified by the state of Wisconsin, whether or not they apply restricted-use pesticides. Training is the responsibility of the University of Wisconsin-Extension Pesticide Applicator Training Program and certification the responsibility of WDATCP. The current regulations and recommendations for herbicide use in Wisconsin are set out each year in UW-Extension Bulletins A3646 *Field Crops Pest Management in Wisconsin* and A3422 *Commercial Vegetable Production in Wisconsin.*

The Wisconsin Groundwater Law

The Wisconsin Groundwater Law (Chapter 160 of Wisconsin statutes) governs response to pesticide contamination of groundwater. It was enacted in May 1984. This law provides a comprehensive legal framework for the protection of groundwater resources. It does many things, but two of its most important provisions set groundwater quality standards and establish the roles of the various state agencies in groundwater protection.

Groundwater standards

■ ***Wisconsin standards: the Enforcement Standard and the Preventive Action Limit***

All regulatory programs for groundwater protection in Wisconsin are based on groundwater quality standards. For each actual or potential contaminant, such as a pesticide, two concentration-based standards are established.

The Enforcement Standard (ES) is the concentration of regulatory and health significance. If the chemical's concentration exceeds the ES, the state must take action to regain compliance with the standard. If a well test


Groundwater quality standards help assure safe drinking water.

Table 1.1. Standards established for five commonly used herbicides.

Compound	Enforcement Standard	Preventive Action Limit
Atrazine (plus 3 metabolites)*	3 ppb	0.3 ppb
Alachlor	2 ppb	0.2 ppb
Cyanazine	12.5 ppb	1.25 ppb
Metolachlor	15 ppb	1.5 ppb
Simazine	4 ppb	0.4 ppb

* The three metabolites of atrazine included in the standards are deethylatrazine, deisopropylatrazine, and diaminoatrazine.

indicates that the water exceeds the ES, the well owner is advised that the water should not be used for drinking or cooking purposes.

The Preventive Action Limit (PAL) serves as a warning level. When the PAL is exceeded, the state is required to evaluate the situation and ensure that the ES is not exceeded. The PAL is set at 10% of the ES for potentially carcinogenic substances and 20% of the ES for other compounds.

The DNR and the Wisconsin Department of Health and Family Services (DHFS) are responsible for setting groundwater quality standards. The DHFS collects and studies all toxicological information related to compounds of groundwater concern and recommends standards to DNR. The DNR then holds public hearings on the proposed standards, and ultimately, when it adopts them, they are incorporated into the Wisconsin Administrative Code under NR 140.

Establishing new groundwater standards is an ongoing process based on a prioritized list of compounds. Table 1.1 shows the standards established for five commonly used herbicides. The standards are given in parts per billion (ppb).

■ *Federal standards: Maximum Contaminant Levels*

The EPA's standards for pesticides in water supplies are called Maximum Contaminant Levels (MCLs) and are also based on health effects. The procedures used by EPA and DHFS to develop standards differ slightly, so the two agencies may come up with slightly different standards for the same compound. However, once EPA establishes a MCL for a compound, DHFS generally adopts the EPA's standard unless it can be shown that a different level is warranted.

Agency responsibilities

Under the Groundwater Law, state agencies have the responsibility to protect groundwater from the substances and activities that they regulate. Under this system the following agencies are responsible for specific types of substances:

- the Wisconsin Department of Transportation (DOT) for road salt
- the Department of Workforce Development (DWD) for septic systems
- DNR for a number of potential contaminants such as solid and hazardous wastes and petroleum
- DATCP for pesticides and fertilizers.

Both the Wisconsin Groundwater Law and administrative rule ATCP 31 describe the measures DATCP must take in response to groundwater contamination by pesticides. For groundwater contamination above the ES, DATCP must prohibit the activity or practice which caused the contamination. For levels of contamination below the ES, the appropriate regulatory response is more complex. As stated in ATCP 31.09, any substance-specific groundwater protection rule "shall be designed, to the extent technically and economically feasible, to minimize the level of pesticide substance in groundwater and maintain compliance with the preventive action limit for the pesticide substance state-wide."

Point source pesticide contamination results from events such as spills, improper disposal of containers, back-siphoning into wells, and other more concentrated sources.

Herbicides in Wisconsin groundwater

Herbicides have been found in Wisconsin groundwater. Some of the contamination originated from point-sources such as spills, while in other cases normal field use has been shown to be the source. The herbicides that have been detected in groundwater include atrazine, alachlor, and metribuzin.

Sources of pesticides contaminating groundwater

■ ***Point sources***

Pesticide contamination in groundwater can be divided into point source and nonpoint source contamination. Point source pesticide contamination results from events such as spills, improper disposal of containers, back-siphoning into wells, and other more concentrated sources. Spills can be large catastrophic events or smaller, repeating occurrences at loading sites such as leaks from application equipment.

Pesticide contamination from point sources often results in comparatively high concentrations in groundwater and detections of more than one pesticide, such as would result from the spill of a tank-mix, for example. Pesticides not normally found in groundwater as a result of field use can be found after a spill.

■ ***Non-point sources – normal field applications***

Non-point source contamination is the result of pesticide applications over broader areas such as an agricultural field. The source of contamination is diffuse, resulting in relatively low concentrations in groundwater. Generally only pesticides that are quite soluble, persistent and weakly bound to soil particles pose a risk to groundwater as a result of normal field applications.

Groundwater pollution from normal field use is more likely to occur in areas that have soil and geologic conditions that allow comparatively rapid leaching of chemicals through the soil to the water table. Coarse-textured soils, shallow soils, a groundwater table near the surface and fractured bedrock are conditions that contribute to susceptible sites.

Herbicides detected in groundwater

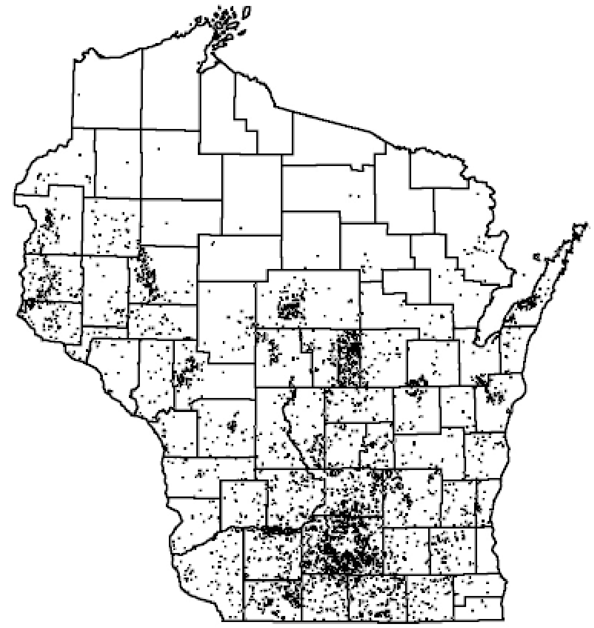
Since the early 1980s, a number of groundwater sampling programs have been conducted for pesticides (Table 1.2). Most have focused on atrazine; however, some sampling programs have been directed at or have had the ability to detect other compounds. Some of these programs have been statistically designed for research, while others have been more for public service. Still other programs

Table 1.2. Selected sampling programs for herbicides in Wisconsin groundwater.

	Years	Wells sampled
DATCP Groundwater Monitoring Project for Pesticides (Postle, 1995a)	1985 - present	ongoing
DATCP Grade A Dairy Well Surveys (LeMasters and Doyle, 1989)	1988	534
DATCP Rural Well Survey	1990	2187
DATCP Atrazine Rule Evaluation Survey (LeMasters and Baldock, 1997)	1994, 1996	429
DATCP Alachlor Survey (Vanden Brook, 1994)	1994	669
DATCP Exceedence Survey (Postle, 1995b)	1995-1997	120 wells/year
Wisconsin State Lab of Hygiene Triazine Testing	1990 - present	ongoing
Wisconsin Priority Watershed Well Water Testing, selected watersheds	1990 - present	~3500, ongoing

have sampled around areas of known contamination. In total, over 18,000 wells in Wisconsin have been sampled for one or more pesticides.

Figure 1.1. Wisconsin wells with atrazine detections.



Source: WI Department of Agriculture, Trade & Consumer Protection - ARM Division (7/97)

■ *Atrazine*

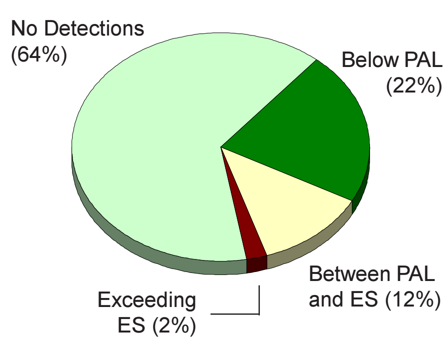
Atrazine (AAtrex and other trade names) use began in Wisconsin in the late 1950s. It became the most commonly used pesticide in the state. In 1990, atrazine was applied to 56% of the corn acreage (2,116,000 acres) and 58% of the sweet corn acreage (93,800 acres) in Wisconsin. (Wisconsin Agricultural Statistics Service 1991)

Groundwater testing for atrazine began in the early 1980s when DNR staff conducted limited sampling in vulnerable areas. From 1984 to1996, thousands of wells were tested for atrazine. Over this same time period, several things happened that influenced atrazine testing and the interpretation of the results:

- In the mid-1980's, improvements in analytical techniques lowered the limit of detection for atrazine to 0.15 ppb from 1.0 ppb.
- In 1988, the state health advisory level for atrazine changed from 215 ppb to 3 ppb.
- In 1991, water samples began to be analyzed for three metabolites, or chemical break-down products, of atrazine in addition to atrazine itself.
- In 1992, three metabolites (deethylatrazine, deisopropylatrazine, and diaminoatrazine) were included in the atrazine groundwater standard.

These changes have led to more atrazine detections and more instances where the groundwater standard has been exceeded.

Figure 1.2. Wisconsin private wells sampled for atrazine.



Source: WI Department of Agriculture, Trade & Consumer Protection - ARM Division (7/97)

As of January 1997, DATCP had atrazine sample results for 18,606 wells in its database. Atrazine was found in samples from 6,733 (36%) of these wells (Figure 1.1). Of the 6,733 detects, 4,052 wells were below the PAL for total chlorinated atrazine (0.3 ppb), 2,278 were between the PAL and ES (0.3 ppb - 3.0 ppb), and 401 exceeded the ES (3.0 ppb (Figure 1.2). Since this database reflects a variety of sampling programs of different designs, it should not be considered unbiased. The percentage of contaminated wells in this database may be higher than the real percentage for the entire state because some sampling programs searched for areas where contamination was likely.

The two unbiased well sampling programs that have been conducted for atrazine in the state are the DATCP Grade A Dairy Well Water Quality Survey (LeMasters and Doyle, 1989) and Phase 1 (1994) of the DATCP Atrazine Rule Evaluation Survey (LeMasters and Baldock, 1997). From the Grade A Survey, a statistical estimate was made with 95% confidence that between 9 and 15% of Grade A dairy wells in Wisconsin contained atrazine. In the South Central Crop Reporting District, it was estimated that between 19 and 39% of the Grade A wells contained atrazine.

In the Atrazine Rule Evaluation Survey, a statistical estimate was made with 95% confidence that between 8 and 16% of the wells in Wisconsin

Figure 1.3. Wisconsin wells with alachlor or alachlor ESA detections.

Source: WI Department of Agriculture, Trade & Consumer Protection - ARM Division (7/97)

contained atrazine. Between 1 and 3% of the wells in Wisconsin were estimated to exceed the 3.0 ppb ES.

■ *Alachlor*

Alachlor (Lasso, Micro-tech, and other trade names) is a popular herbicide in Wisconsin. In 1990, it was applied to 1,046,500 acres in Wisconsin - 24% of all field corn acres, 55% of all sweet corn acres and 17% of all soybean acres (Wisconsin Agricultural Statistics Service 1991).

In 1994, DATCP conducted a survey of alachlor and its metabolite ethane sulfonic acid (ESA) in at-risk wells in Wisconsin. The wells that were selected had a previous detection of atrazine or high nitrates and were located in areas of frequent alachlor use. This survey was not designed to provide unbiased statewide results, but rather to evaluate alachlor and ESA problems in at-risk wells (Vanden Brook 1994).

The survey was conducted in two parts. In part one, 669 samples were screened using an immunoassay test. The presence of alachlor or its metabolite ESA was detected in 300 of the samples.

In part two, samples from 293 of the wells with detections were analyzed using conventional gas chromatography methods. Alachlor was detected in only 12 of the 293 samples with concentrations ranging from 0.21-6.9 ppb. ESA, however, was detected in 206 of these samples with concentrations ranging from 1.1- 27 ppb (Figure 1.3). Only two well samples exceeded the 20 ppb state health advisory level. (An ES for alachlor ESA has not yet been adopted.) These results indicate that alachlor ESA is a frequent contaminant in at-risk wells in Wisconsin, but alachlor itself is not.

■ *Metribuzin*

In 1990, metribuzin (Sencor, Lexone) was applied to 96,000 acres in Wisconsin – 47,000 acres of soybeans and 49,000 acres of potatoes. These applications included 11% of the state-wide soybean acreage and 74% of the state-wide potato acreage. Of the total use on potatoes in 1990, about 75% occurred in the Central Crop Reporting District (CCRD) where 91% of the potato crop was treated (Wisconsin Agricultural Statistics Service, 1991). The CCRD contains predominately sandy soils which are prone to leaching.

Well testing has shown that metribuzin is a frequent contaminant in groundwater in the Central Sands area of Wisconsin and to a lesser extent in the Lower Wisconsin River Valley (Postle, 1995a). This contamination appears to be the result of use on potatoes in irrigated sandy soils.

Figure 1.4. Wisconsin wells with metribuzin detections.

Source: WI Department of Agriculture, Trade & Consumer Protection - ARM Division (7/97)

As part of the DATCP Monitoring Project for Pesticides, metribuzin has been monitored at 27 irrigated, sandy fields. It has been detected at 21 of the sites (Figure 1.4), but only three sites have exceeded the PAL (25 ppb) and none have exceeded the ES (250 ppb). The highest detect in the project has been 53.5 ppb. The average of all the detects is 1.8 ppb. (Postle 1995)

The DATCP groundwater database contains 86 wells with metribuzin detects. The range in concentration for the detects is 0.1 ppb to 72 ppb, but most of the concentrations are quite low. Only four wells exceed 5 ppb and only two wells exceed the 25 ppb PAL. These two wells were part of a point source investigation. The detections are scattered throughout the state, but the two counties with the most detects are Portage (23 detects) and Adams (16 detects) - counties with predominately sandy soils.

Although the contamination is widespread in parts of the Central Sands, very few detects are above the PAL and none are above the ES (with the possible exception of spills). At the current ES of 250 ppb, there does not appear to be a problem of health or regulatory concern. However, if the standard is ever lowered, the interpretation of these data could change.

■ ***Other herbicides***

Several other herbicides have been detected in Wisconsin groundwater as a result of normal applications on agricultural fields. These include simazine (Princep), metolachlor (Dual), cyanazine (Bladex), bentazon (Basagran), and linuron (Lorox). Concentrations of these parent compounds are generally low with few wells exceeding groundwater standards. Little is known, however, about the metabolites of most herbicides found in groundwater.

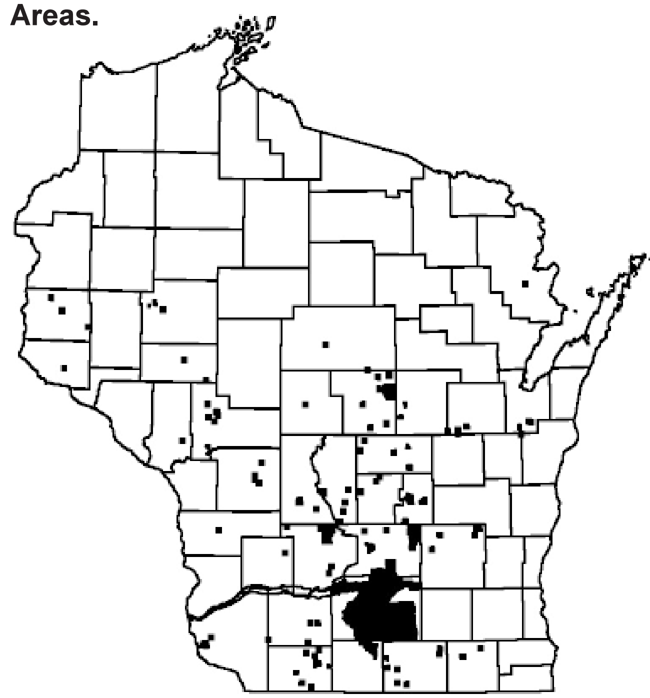
Groundwater protection rules

Wisconsin groundwater protection rules are generated in response to evidence of contamination. A rule has been established for atrazine and rules for other herbicides may be created in the future.

The Wisconsin Atrazine Rule

The original Wisconsin Atrazine Rule, Ch. ATCP 30 (formerly Ag 30) was developed by DATCP in response to increasing evidence of atrazine contamination in groundwater. It took effect in March, 1991. This rule restricted the use of atrazine on a statewide basis to between 1 and 2 pounds per acre, depending on soil texture. It also established one atrazine management area (AMA) in the Lower Wisconsin River Valley with atrazine and six prohibition areas (PAs) in which the use of atrazine was forbidden.

Figure 1.5 Wisconsin Atrazine Prohibition Areas.



Source: WI Department of Agriculture, Trade & Consumer Protection - ARM Division (7/97)

The Atrazine Rule has been amended every growing season since 1991 as continued sampling has found more wells where atrazine levels meet or exceed the ES.

In March 1993, the rate at which atrazine can be applied anywhere in the state was limited at 0.75 to 1.5 pounds per acre (Table 1.3), effectively making the entire state an AMA. An exemption was allowed on seed and sweet corn if a rescue treatment is needed. New PAs have been added and existing ones enlarged each year. As of 1997, there are a total of 96 PAs covering approximately 1.2 million acres (Figure 1.5).

In 1996, five years after its enactment, DATCP conducted a review of the Atrazine Rule to determine if it was successful in reducing atrazine levels in groundwater (Postle et al. 1997). The study indicated that concentration levels of atrazine in groundwater had declined significantly. However, the proportion of wells containing atrazine had not changed significantly. The evaluation concluded that groundwater quality is improving, but new ground-

Table 1.3. Atrazine active ingredient rate limits*.

	- - - - - Statewide atrazine limits - - - - -	
Surface soil texture	**Atrazine used last year**	**No atrazine used last year**
Coarse	0.75 pounds / acre	0.75 pounds / acre
Medium and fine	1.0 pounds / acre	1.5 pounds / acre

* An exception applies to seed corn and sweet corn growers only who find it necessary to use postemergence atrazine as a "rescue" treatment. Total amount of atrazine used at planting and postemergence may not exceed 1.5 lb./a on coarse textured soils and 2.0 lb./a on medium and fine textured soils.

Source: Field Crops Pest Management in Wisconsin-1996. UW Ext. Pub. A3646.

water contamination is still occurring in some cases under current lowered atrazine use rates.

Future groundwater protection rules for herbicides

■ ***Alachlor***

After atrazine, alachlor is the herbicide that is receiving the most attention from a regulatory perspective. Alachlor has occasionally been found above its ES. Alachlor's metabolite, ESA, has also been found in groundwater. The level at which an ES is ultimately set will influence the extent of the problem with ESA. In addition, alachlor is one of the five pesticides for which EPA is requiring Wisconsin to develop a state management plan, described below, as a condition of continued use in the state.

■ ***State management plans for groundwater protection***

In response to groundwater protection programs at EPA, DATCP has developed a generic state management plan for protection of groundwater from pesticides. This generic plan provides a framework for pesticide-specific management plans in Wisconsin. When EPA determines there is a significant risk of a pesticide getting into a state's groundwater, that pesticide's registration can be canceled if the state does not prepare a pesticide-specific management plan to protect groundwater. Under this mandate, DATCP will be preparing pesticide-specific management plans for alachlor, atrazine, cyanazine, metolachlor, and simazine. Since cyanazine, metolachlor and simazine have not been frequently found in groundwater, the management plans for these compounds may not contain regulatory components.

Summary

Pesticide use in Wisconsin is governed by both the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and Wisconsin Pesticide Law and Administrative Rule, Chapter ATCP 29. The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) has primary responsibility for pesticide use and control in the state. The Wisconsin Groundwater Law governs response to pesticide contamination of groundwater. The Groundwater Law mandates that DATCP take action to reduce contamination when concentrations of a pesticide in groundwater exceed a set level called the Enforcement Standard (ES).

Herbicides coming from both point sources and from normal field use at label rates have contaminated Wisconsin groundwater. Atrazine is the herbicide most often detected; it has been found in over 6,700 wells (36% of the wells with tests recorded in the DATCP database). While alachlor contamination is not common, one of its metabolites, ESA, is frequently found in high-risk wells. Metribuzin is often found in the groundwater in areas where potatoes are grown in irrigated sandy soils.

Since 1991, the Wisconsin Atrazine Rule (ATCP 30) has restricted the rate of atrazine applications in the state and prohibited use in areas where atrazine concentrations in well water samples have exceeded the ES. There is not currently a similar rule for any other herbicide, but, under the direction of the U.S. Environmental Protection Agency, DATCP is preparing pesticide-specific state management plans to protect groundwater from alachlor and four other herbicides.

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2 Integrated Weed Management:
Options for Better Crop Production

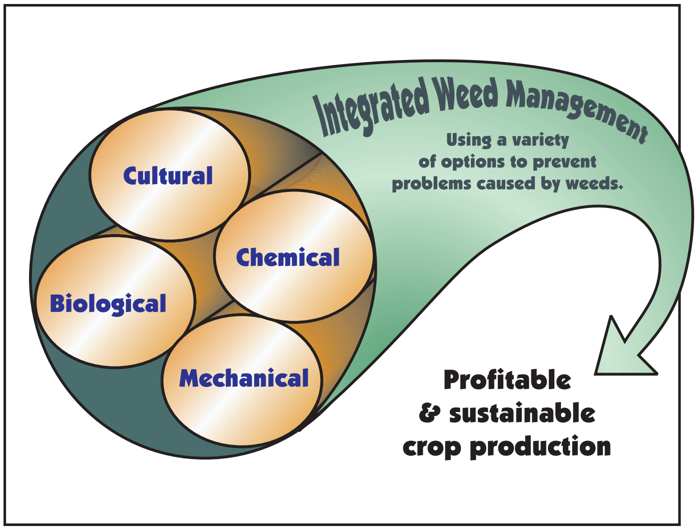
Weeds are a major concern in crop production. Competition from weeds is directly responsible for annual crop loss in the United States of more than $4.1 billion (Bridges, 1992). This chapter discusses the need for an integrated approach to reducing crop losses caused by weeds – an approach that uses a wide range of management techniques to favor the crop and discourage weeds.

Today's weed control practices have largely been developed through herbicide research. Herbicide formulations, application rates, techniques, and timing have been subjects of intense study. Because herbicides are extremely effective for controlling unwanted vegetation, other types of weed control measures, such as mechanical weeding (cultivation), have been de-emphasized for many years. For many farmers, weed control is synonymous with herbicides. Despite decades of wide-spread herbicide use, however, weeds are at least as much of a problem today as they were 50 years ago.

Dependence on herbicides for weed control has brought about many unforeseen problems. Some weeds have become resistant to certain types of herbicides. Concerns over human health, contamination of water resources, increasing populations of particular hard-to-control weed species, and decreasing farm profitability have all been attributed, in one way or another, to a dependence on herbicides. There is an understanding among weed scientists that reliance on any one method of weed management will eventually cause problems.

Weed scientists also realize that no matter what is done to control them, there will always be weeds in crop production. "Plant populations will probably always tend to become resistant to any practice we throw at them," according to Doug Buhler, USDA-ARS Research Agronomist.

Changes in management practices may reduce or eliminate some weed problems, but new weeds will take their place. Any ecological niche in an agricul-



An integrated approach to reducing crop losses caused by weeds – an approach that uses a wide range of management techniques to favor the crop and discourage weeds.

tural system that is available will be filled by a plant species that can exploit its resources. There are thousands of species that could be potential weeds (Buhler, 1995). If a species is removed from an agricultural system, something else will move in to fill that niche. In response, weed scientists are supporting integrated weed management (IWM), an approach that looks for a variety of ways to prevent problems caused by weeds, rather than relying on any one method alone.

IWM follows the basic principles of integrated pest management (IPM), which was developed primarily for managing insect pests. An IPM strategy uses knowledge of the pest's life cycle, population, and relationship with the surrounding environment. It also considers the effects that pest management tactics have on the environment in which the pest lives.

IPM seeks to design a pest control system using the most effective methods available. It does not advocate the elimination of chemical methods for pest control. However, when there is an effective non-pesticide alternative to manage a pest, there is less emphasis on the use of chemical methods. For this reason, IPM is considered to have less impact on natural and economic resources than "standard" pest control strategies.

Principles of integrated pest management (IPM)

According to the tenets of IPM, the role of pest management in an agricultural context is to protect crops from pests that, if present in sufficient numbers, will cause economic damage. IPM seeks to protect the crop by preventing or suppressing pest problems. There are five basic principles to IPM (Bechinski et al., 1992).

Principle 1: There is no cure-all in pest control.

Dependence on any single pest management method can have undesirable effects. For instance, as a result of depending on the same insecticides for pest control year-after-year, some insects have become resistant to chemicals that were once able to control them. Similarly, some weeds are now resistant to particular herbicides. The IPM approach combines control methods, balancing the strengths of each method against any individual weaknesses, ultimately providing an effective pest management strategy. Thus the over-reliance on any one method is avoided.

Principle 2: Tolerance – the eradication of a pest is seldom necessary or desirable.

Crops can tolerate a certain degree of pest infestation without adverse effects. The goal of an IPM strategy is to keep pest populations below levels where they cause economic damage. Reducing the pest level further only serves to decrease profits due to increased input costs associated with the higher degree of pest control. This is why pursuing the total eradication of weeds in a crop regardless of cost defies common sense. Rarely does an IPM strategy include the total elimination of a pest.

Principle 3: Determine and correct the *cause* of the pest problem.

Rather than concentrating only on the pest, the conditions that allowed the species to become a pest should also be addressed. Correcting the cause of a pest problem requires an understanding of the pest's biology and ecology so that the crop environment can be manipulated to the advantage of the crop and to the disadvantage of the pest. In addition, an understanding of other potential pests is needed so that the changes made to the cropping system do not favor some other pest.

For weed management, Buhler (1996) has interpreted this principle as emphasizing the "integration of techniques to anticipate and manage problems rather than reacting to them after they are present." That is, the approach taken in weed management should be prevention of weed problems.

Principle 4: The natural enemies of pests are important.

This principle appears to apply more to insect pest management than to weed management. Often when trying to manage a pest with a chemical method, the pests' natural enemies are also "managed." Without the natural enemies present, secondary outbreaks of pests are often larger than the initial pest outbreak. When a thorough understanding of the pests' biology and ecology is known, appropriate measures can be taken to preserve the pests' natural enemies. Furthermore, the crop environment may be manipulated to favor the natural enemy.

Principle 5: Good farming practices that promote crop growth are important.

A healthy, vigorously growing plant can tolerate pests better than a weak, stressed plant. IPM takes full advantage of farming practices that enhance plant growth and development. Anything that increases the competitive abilities of a crop will increase its tolerance to a pest. Time of seedbed preparation, planting date, seeding rate and proper soil fertility are a few examples of farming practices that enhance plant growth and development.

First steps in weed management

Currently, there is a much better understanding of insect pest life cycles than of most weed life cycles. Much current weed research focuses on gaining a better understanding of weed ecology and biology. As this information becomes available, it will make it possible to design more effective control systems following the IPM principles. This manual, however, describes weed control options that are available for use by farmers in integrated weed management systems today.

The methods used in IPM can be biological, cultural, mechanical and/or chemical (Wilson, 1992). Cultural, mechanical, and chemical tools for weed control are discussed in the next three chapters of this manual. As only a few biological methods for weed control (e.g., using the natural enemies of weed species) have been developed and none are widely available, they are not included in this manual. Before looking at the specific control methods in the following chapters, the reader should have a knowledge of some of the basic weed-problem identification tools described below.

Weed identification

Proper identification of a weed is essential for its control. An unknown weed cannot be properly managed. Weed species are different and as such must be managed differently. Grassy weeds are not all alike, nor are broadleaf weeds.

Control options for one species are not always effective on another. For example, a crop rotation with alfalfa "is a good long-term way to control wild proso millet. Alfalfa is able to maintain a competitive edge over wild proso millet seedlings, and regular mowing prevents seed production..." (Doersch et al., 1987). However, this strategy will not be as effective in the control of quackgrass because it tolerates mowing and spreads primarily through rhizomes. Another example is controlling grassy weeds versus sedges. These species look alike, but are controlled by very different methods. Correct weed identification is critical to weed management.

Crop scouting and weed mapping

Crop scouting and weed mapping can be time-consuming, but they can also yield important information about crop condition and pest distribution in a field. Crop scouting is a systematic method of monitoring a field with the goal of providing a complete, accurate and unbiased assessment of pest populations. Scouting provides a grower the opportunity to apply a control measure to a pest problem before it causes economic damage and leads to future pest problems.

Mapping areas of fields where weed problems occur is an important component of the scouting process. Development of a weed map does not have to be a major investment in time. Maps can be based

Crop scouting is a systematic method of monitoring a field with the goal of providing a complete, accurate and unbiased assessment of pest populations.

on observations made from the tractor or combine during field operations, or maps can be developed using high technology techniques such as geo-positioning satellites (GPS).

Mapped weed information is a useful tool when planning future crop production strategies and allows a grower to monitor increases or decreases in weed pressure over an extended period of time. In addition, marking areas of increased weed pressure gives reference points for future control measures. For instance, if an area of Canada thistle or quackgrass is left uncontrolled, it will quickly spread to become a major problem. If this area is mapped and appropriate control measures applied, the weeds can be managed. The map will serve as an important evaluation tool to monitor the success or failure of weed management practices.

An added benefit of crop scouting and weed mapping is that small areas of weed infestations can be spot-sprayed with a herbicide. Spot spraying, rather than treating the whole field, is only possible if such weedy areas had been mapped in some fashion the previous year or scouted in the current year. Weed maps will guide the applicator to the area that requires the herbicide application. The result

Useful Plant Identification References

Weed Science Society of America. This web-site contains images and descriptions of approximately 200 weed species. It also includes information on herbicide injury symptoms, herbicide resistance, links to herbicide label, etc. The site address is http://piked2.agn.uiuc.edu/wssa/

Weeds of the North Central States. Contains 303 pages of black and white line drawings. Complete key based on flower color. Available through County Extension offices.

Ontario Weeds. Contains 315 species with black and white line drawings and 28 pages of color plates. Available from Publications Ontario, 50 Grosvenor St., Toronto, Ontario, Canada M7A 1N8.

Weeds of Nebraska and the Great Plains. Contains 589 pages with color plates of mature specimens and detailed drawings or photo inserts of seed, seedling, leaf or other key part. Available from the Nebraska Department of Agriculture, Bureau of Plant Industry, PO Box 94756, Lincoln, NE 68509.

A Field Guide to Wildflowers. Includes 420 pages arranged by flower color. Each chapter with some drawings in color. Available in the nature section of most bookstores.

Weeds of the United States. CD-ROM includes 1600 photographs, 300 distribution maps and complete text descriptions. Requires Windows 3.1 or higher, 486 processor with 8 MB RAM and a 2x CD-ROM drive. Available from Southern Weed Science Society, 1508 W. University Ave., Champaign, IL 61821-3133. This weed identification guide is also available in printed form. Call for information (217) 352-4212.

Common Weed Seedlings of Michigan. This is a 16 page bulletin that includes 11 grasses, 1 sedge, and 21 broadleaf weeds. It has a simple key for the grasses and a brief description of each weed. Each weed has a color photograph of the seedling plus two smaller photographs of key features. Order bulletin E-1363 for $1 per copy (includes postage) from MSU Bulletin Office, Room 10B Agriculture Hall, East Lansing, MI, 48824-1039.

Seedling Identification Key. This bulletin is a simple key for the grasses and broadleaf weeds. It is a 3 page publication that keys 22 broadleaf weeds and 14 grassy weeds. It also includes some botanical terminology to help aid with identification. Order bulletin AG-FO-2928 from MES Distribution Center, 20 Coffey Hall, 1420 Eckles Ave., Saint Paul, MN 55108-6069; (612) 625-8173.

can be reduced herbicide application costs and the prevention of serious weed infestations.

More detailed information on crop scouting can be found in UW-Extension Publication A3547 *Scouting corn : A guide for Wisconsin corn production* (Doll et al., 1995).

Weed prediction techniques

The ability to predict future weed pressure would be an extremely useful tool in weed management. This is an active area of research being investigated by many weed scientists. While there are many predictive systems to choose from, few are "user friendly" enough to be readily adopted by farmers. Some promising methods of predicting weed emergence rely on computer software. One relatively simple technique is available for Wisconsin farmers. This technique is called PREDICT.

PREDICT (Harvey, 1992) is based on observations from small untreated check areas left in the field. These areas serve to gauge weed biomass and to determine weed species composition. Untreated check areas are used because it is impossible to determine the actual weed species and density based on weeds that escape herbicide treatment in fields due to the effect of the herbicide on weed populations and dynamics. The biomass estimates are used to predict crop loss from weed competition. Crop loss estimates are then used to determine the most cost-effective control measure. While leaving untreated check areas in a field may make a farmer uncomfortable, it will provide very useful information for the control of future weed infestations. Complete instructions for PREDICT are provided in Appendix A.

Summary

Weeds are and will continue to be a major challenge to crop production. Dependence on any one type of weed control method alone will lead to unforeseen problems. Use of an IWM approach that combines cultural, mechanical and/or chemical strategies will lead to better long-term weed control. IWM strategies promote crop growth and prevent weed problems following the principles of IPM. Knowledge of weed populations gained through scouting and mapping is central to effective weed management.

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3

Cultural Practices for Managing Weeds

Crop production practices that favor crops and discourage weeds

Crop production practices directly impact weeds and their management. Both crops and weeds compete for the same resources: light, water, and nutrients. Variations in cultural practices such as tillage for seedbed preparation, crop rotations, nutrient management, planting date and seeding rate affect competition for these three resources. The proper manipulation of crop production practices can greatly enhance a crop's ability to succeed over weeds. This chapter identifies crop production practices that prevent weeds from getting into fields or promote crop competitiveness over weeds.

Preventing weed dispersal

In the recent past, farmers have been able to control most weed species with herbicides. This success in controlling weeds after they appear in fields has obscured the importance of preventing their introduction in the first place. The best line of defense against the invasion of new weed species is to prevent their spread from one field to another.

Weeds are prolific seed producers (Table 3.1). Furthermore, many weed seeds can remain viable for a long time in the soil (Table 3.2). Preventing new species introductions to cropland is important for weed management.

Some factors that contribute to the movement of weeds are beyond our control. Natural processes such as transport of seed by animals, wind, and water, can bring new weed species into an area. Such natural introductions are rarely large enough to create a weed problem initially. However, if not identified and managed early, these new weed species can increase to become a problem. As weeds rarely move great distances naturally, human activities on the land do more to spread weeds than any natural processes. Ways to avoid weed spread are described in the following sections.

Table 3.1. Approximate number of weed seeds per plant.

Yellow nutsedge	2,400
Barnyardgrass	7,000
Giant foxtail	10,000
Velvetleaf	17,000
Common lambsquarters	72,000
Redroot pigweed	117,000
Black nightshade	178,000

Adapted from Ross, M. A. and C. A. Lembi. 1985. *Applied Weed Science*.

Table 3.2. Maximum longevity of weed seeds buried in the soil.

Species	Years
Quackgrass	6
Shattercane	10
Giant foxtail	20
Canada thistle	21
Velvetleaf	40
Common lambsquarters	40
Redroot pigweed	40

Adapted from Ross, M. A. and C.A. Lembi. 1985. *Applied Weed Science*.

Clean equipment

The most common mechanism of weed seed introduction to fields is transport by tillage and harvest equipment. Evidence of this is that new weed species often appear at the entrance to a field. While it can be time consuming, cleaning equipment with compressed air, steam or water before moving from a weedy field to a "clean" field can stop the spread of weeds.

Cleaning equipment is especially important when trying to limit the spread of hard-to-control weeds such as wild proso millet and woolly cupgrass. These weeds, once established, can create years of weed control problems. Twenty minutes of equipment sanitation can help deter 20 years of weed control work.

Weed-free crop seed and livestock feeds

Weed-infested crop seed and animal feed can also introduce new weeds to farm fields. While certified and commercial crop seed is cleaned of weed seed, bin run (saved) seed is usually not. Bin run seed from a field that had weed problems will spread those weeds to the field where it is planted. If a grower is using saved seed, it is important to pass it through a sieve or fanning mill before planting in order to remove most weed seed. If a grower has exchanged bin run seed with another grower, the seed should be cleaned before planting, but it is unlikely that 100 percent of the weed seed can be removed, particularly in small grains. Remember that it only takes one seed to start a new infestation. Weed seed screenings should be destroyed by burning or burying.

Purchased animal feed and straw, as well as animal feed and straw grown on the farm, can be a source of weed seeds. Generally, animal feed purchased from a dealer is free of weed seed. However, weed seed contamination of feed does occur. In Wisconsin, common cocklebur was introduced to farms by way of cotton seed purchased as a protein source for dairy cows. The cotton seed was contaminated with cocklebur seed. Some cocklebur seed survived the digestive process and was spread to fields in manure, resulting in cocklebur infestations. One way to lessen this problem is to compost livestock manure.

Rotating crops

Monoculture is the repeated production of the same crop in the same field over an extended period of time. It is a fairly simple crop production system that has found favor with many growers. However, it can create numerous problems such as increased pest pressure, increased soil erosion, and reduced farm profit. Continuously growing the same crop with the same management practices leaves a niche for pests that are adapted to those conditions. A field that has never been rotated is a field where pest management is the most difficult. Weeds, insects and disease all become difficult to control without the use of pesticides. As a result, monoculture creates a dependency on pesticide use.

Many growers are fully aware of the problems associated with monoculture and have moved toward a diversified crop rotation.

Wisconsin's Noxious Weed Laws

Some weeds are such problems that the state of Wisconsin has passed legislation to prevent their spread. The state legislature has determined that three perennial weeds - Canada thistle, field bindweed and leafy spurge - are to be considered noxious and must be "destroyed". Landowners can be billed for the control of these weeds if they do not comply with the law. In addition many counties have declared other weed species noxious at the town or township level.

Another, lesser-known law that tries to prevent the spread of weeds is the Wisconsin Feed Law. This law contains language that regulates the amount of viable weed seed that can be in animal feed. The Feed Law states that feed labels must "clearly and permanently" indicate if the feed contains more than 0.01% of viable noxious weed seed or more than 0.25% of other viable weed seed. Canada thistle, wild mustard and quackgrass are identified as noxious weeds in this law.

A third law is concerned with "nuisance weeds". This law prohibits the distribution, selling or planting of nuisance plants or seeds of "any non-native member of the genus Lythrum, (purple loosestrife) and hybrids thereof and multiflora rose."

As of yet, no noxious or nuisance weeds have been eradicated. The passage of laws targeting them has, however, "served to highlight their aggressive nature of growth and difficulty of control"(Doll, 1990).

Enforcement of noxious weed laws is often lacking, and should be expanded. Doll (1993) surveyed agricultural extension agents and found, "The Wisconsin noxious weed law has been helpful to some local governments, a few have used it to excess, but most have seemed to ignore it."

Crop rotations disrupt weed life cycles

Crop rotation is a key means for managing existing weeds, as well as other pest problems. The more dissimilar the crop and weed life cycles are, the more difficult it is for a weed species to develop into a severe problem. When the environment is regularly disrupted by switching to a crop with a different life cycle (e.g., from a summer annual to a winter annual or a perennial) and different field operations, it becomes harder for a weed species to proliferate. Crop rotation has a similar effect on other pest problems such as insects and disease.

If a crop is grown in the same place for an extended period of time, there are certain predictable weeds with similar lifecycles that will be found in association with it (Table 3.3). For example, alfalfa competes well with annual weed species like foxtail and common lambsquarters. After several years, however, an alfalfa field becomes the perfect environment for perennials such as dandelions and quackgrass. Conversely, dandelions and quackgrass do not do as well in annual crops like corn and soybean because of the annual tillage operations used for seedbed preparation.

Rotating crops can increase profitability

Numerous studies have shown crop rotation increases yields (WICST, 1996; Gumz et al., 1995; Posner et al., 1994). Yields of first-year corn following alfalfa almost always exceed second and third year corn yields, and always exceed continuous corn yields. Crop rotation often results in higher profits than with monoculture because of the higher yields coupled with lower production costs due to reductions in pesticide and nutrient inputs.

Crop yields and economic returns for a continuous corn system versus a corn/soybean rotation versus a corn-soybean-wheat/red clover rotation are shown in Table 3.4. These data were obtained from the first five years of the Wisconsin Integrated Cropping Systems Trial (WICST). The trial is comparing the profitability of three cropping systems and is planned to last at least 12 years.

To date, the corn-soybean rotation has been slightly more profitable than the corn-soybean-small grain/red clover rotation, which in turn has been more profitable than continuous corn. The corn-soybean rotation has consistently had higher yields and profits than continuous corn. In contrast, the corn-soybean-small grain/red clover rotation, which uses

Table 3.3. Common crops and associated weed species.

Crop	Life cycle	Associated weeds
Corn	Summer annual	Wild proso millet Foxtails Lambsquarters Velvetleaf Fall panicum
Soybean	Summer annual	Foxtails Lambsquarters Eastern black nightshade Common ragweed Velvetleaf
Alfalfa	Perennial	Quackgrass Dandelion
Winter wheat	Winter annual	Shephard's purse Field pennycress

no herbicides or purchased fertilizer, had depressed yields for the first two years of this research. It then had the highest profits in 1994, 1995, and 1996. Higher yields and better wheat prices were responsible for the profit increase.

Using cover crops

Cover crops have been used successfully for years to control soil erosion, recycle nutrients and improve soil tilth. They can also suppress weeds by both physically and chemically interfering with their growth.

Weed suppression

When grown in dense stands, cover crops control weeds by physically out-competing them for light, water and nutrients. Cover crops can also form dense residue mats that serve as weed-suppressing mulches.

Examples of weed-suppressing cover crops are foxtail millet, buckwheat, rye, sorghum, sudangrass, sweet clover, sunflower, barley, soybeans for feed, cowpeas, and clover (Ross and Lembi 1985). If not managed properly, cover crops such as sweet clover, hairy vetch and medic can become weeds in subsequent years (Stute, 1995).

Allelopathy

Some cover crops have a chemical effect on certain weed species. Allelopathy is the production of chemicals by a plant that inhibit the growth of other plants nearby. This process holds promise for future weed control strategies. There are currently over 50 weeds and 39 crop plants know to have allelopathic properties, according to A.R. Putnam (personal communication, 1996).

Rye is a common Wisconsin cover crop with allelopathic effects. Sowing rye in the fall and then killing it prior to planting with either a mowing or non-selective herbicide application releases allelopathic chemicals. The allelopathic chemicals lose their effectiveness, however, if they are killed by tillage (Doll and Bauer, 1991). The allelopathic chemical released by rye, DIBOA, which breaks down into another allelopathic chemical called BOA, strongly inhibits the germination and seedling growth of broadleaf weed species. Both redroot pigweed and common lambsquarters are suppressed for 30 to 60 days depending on rainfall (Putnam et al., 1989).

While complete weed management systems utilizing allelopathic plants are not fully developed, "The failure to consider and utilize the competitive abilities of crop plants results in an incomplete weed control program" (Ross and Lembi, 1985).

Table 3.4. Crop yields and gross margins* for three cash cropping systems at the Arlington Research Station and Lakeland Agricultural Complex, 1992 - 1996.

	Average of 1992-96 (per acre)
Arlington Research Station:	
Continuous corn	
Corn yield	144 Bu
System gross margin	$ 144
Input costs	$ 181
Corn-soybean	
Corn yield	156 Bu
Soybean yield	51 Bu
System gross margin	$187
Input costs	$137
Corn-soybean-wheat/red clover	
Corn yield	123 Bu
Soybean yield	52 Bu
Wheat yield	50 Bu
System gross margin	$188
Input costs	$ 84
Lakeland Agricultural Complex:	
Continuous corn	
Corn yield	118 Bu
System gross margin	$113
Input costs	$167
Corn-soybean	
Corn yield	120 Bu
Soybean yield	50 Bu
System gross margin	$180
Input costs	$111
Corn-soybean-small grain/red clover	
Corn yield	103 Bu
Soybean yield	44 Bu
Oat yield	49 Bu
System gross margin	$172
Input costs	$75

* Gross margins are gross returns (market value of crops) minus variable (seed, fertilizer, pesticides, custom operations, etc.) costs.

Source: WICST Notes, Winter 1996. UW-Madison Department of Agronomy.

One precaution about cover crops should be noted. If not managed properly, cover crops can deplete soil moisture. However, many farmers feel this can be overcome by late fall or early spring kill of the cover crop (Mallory, 1994).

Preparing the seedbed with pre-plant tillage

A major benefit of tillage in today's cropping systems is weed control. Preplant tillage, including both primary and secondary tillage, allows for crop establishment without competition from weeds. Primary tillage is the initial groundbreaking with a moldboard, chisel or disk. Secondary or spring tillage, is seedbed preparation - leveling and breaking up soil clumps. This can be done with various equipment, including the cultimulcher, field cultivator, and finishing disk.

Preplant tillage effectively manages annuals, biennials and simple perennial weeds because it kills the underground portion of the plant and buries germinating and established weeds. It also limits future weed problems by preventing established weeds from setting seed.

Even though tillage removes the first flush of annual weeds, their populations persist because they can complete their life cycle and produce seed during the growing season, between tillage operations. The major source of annual weeds is from seeds in the soil. The plow layer can contain millions of weed seeds per acre. Due to the effects of tillage and seeds killed from insects and disease, etc., it is estimated that only 2 to 6% of weed seeds develop into weed seedlings (Wilson, 1988). While tillage does not directly kill weed seeds, it can bury them in an unfavorable environment where they may not germinate. Conversely, tillage can have a detrimental effect by bringing old weed seed up into a favorable germination environment.

Creeping perennials such as quackgrass can be controlled with tillage. Inverting the soil with tillage controls the above-ground portion of the weed and brings rhizomes to the soil surface to desiccate. The drier the soil, the more effective tillage is for controlling weeds. Weeds are more likely to survive if conditions are wet during or shortly after tillage. If creeping perennials produce seed during the growing season, that seed can be spread throughout the field by tillage operations.

Timing tillage operations for maximum weed control

Timing seedbed preparation is an important consideration in weed management. The optimum timing for crop emergence does not often coincide with the optimum timing for weed control. The timing of seedbed preparation is often a balance between getting the crop planted as early as possible for highest yield and tilling as late as possible to control the spring flush of weeds. Weed seed germination depends on variable factors: length of seed dormancy, adequate soil moisture and temperature, (Buhler and Gunsolus, 1996).

In Wisconsin, crops need to be planted as early as possible to maximize yield. If one were attempting just to control weeds, tillage should occur after the spring flush of weeds. Secondary tillage offers a compromise. Secondary tillage operations are often done just prior to planting to dislodge weeds that have germinated and emerged. Timing the secondary tillage operation for maximum weed control can be tricky because germination conditions differ among weed species. However, if a farmer knows what weed species are present in a field, Figure 3.1 may be helpful for determining when the secondary tillage operation should occur. It categorizes weeds based on the time of their initial emergence. (It does not, however, show the length of the weed seed germination period.)

For example, if a field had weed species from early groups, such as 0 through 2, but none from later groups, such as 3 through 7, a tillage operation after group 2 starts to emerge should control most of the problem weeds. However, if a field had weed species from those same early groups and from a later group, such as 5, the tillage operation would have to be delayed until weeds from the later-emerging group appeared. If the secondary tillage operation is mis-timed, then rotary hoeing, as discussed in the next chapter, is post-plant tillage option for managing weeds.

Conservation tillage systems create different weed control challenges

Reducing preplant tillage in a cropping system will dramatically affect weeds and their control. Weed populations respond quickly to changes in crop production practices. "Weeds are successful because of their genetic diversity, which gives them the ability to adapt and take advantage of conditions created by crop production systems" (Buhler 1995).

In the pre-herbicide years, problem weeds were annuals and creeping perennials that could survive tillage operations. As herbicides became prominent weed control tools, weeds that can withstand both tillage and herbicide applications, such as wild proso millet, woolly cupgrass and triazine resistant broadleaves, appeared as problems. New weeds will

Figure 3.1. Relative emergence and green-up sequence of common weeds of summer annual crops.

Previous fall (Winter annuals & biennials)	Early spring - - - - -						Late spring
Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Horseweed	Foxtail barley	Quackgrass	Smooth brome	Canada thistle	Green foxtail	Black nightshade	Fall panicum
Downy brome	Kochia	Orchardgrass	Woolly cupgrass	Giant foxtail	C. milkweed	Wirestem muhly	Crabgrasses
Field pennycress	Prostate knotweed	Giant ragweed	Velvetleaf	C. cocklebur	Hemp dogbane	Shattercane	Morningglories
Shepherd's purse	Wild mustard	C. lambsquarters	C. ragweed	Yellow nutsedge	Barnyardgrass	C. sunflower	Jimsonweed
Biennial thistles	Dandelion	P. smartweed	Wild buckwheat	Redroot pigweed	Yellow foxtail	Venice mallow	
Wild carrot	Russian thistle	Wild oats			Wild proso millet	Waterhemp	
Dandelion (from seed)	White cockle	Hairy nightshade					
	Prior to crop planting		About the time of crop planting			After crop planting	

Source: Buhler, D. D. et al., 1996. Relative emergence of weeds of corn and soybean. Iowa State University Extension Pub. SA11.

develop with the spread of conservation tillage systems such as chisel plowing and no-till.

Conservation tillage is defined in this publication as any cropping system that leaves at least 30% of the soil surface covered with plant residue from the previous crop and maintains that cover following planting of the succeeding crop. Ineffective weed control is a major factor limiting the widespread adoption of conservation tillage, especially no-till (Gebhardt et al., 1985). People who have tried no-till and had poor weed control often have not continued. Other farmers have decided not to use no-till because of what they have heard about the potential weed problems.

While weed control in conservation tillage systems is different, it is not necessarily more difficult. Scouting for new weeds that appear in conservation tillage systems and planning for changes encountered will help avoid weed problems.

Helpful references on weed control in conservation tillage.

- *Controlling weeds in conservation tillage corn production.* R.E. Doersch, and D.D. Buhler. 1989. University of Wisconsin Extension. Bulletin A3425.
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- *The economics of alternative tillage systems, crop rotations, and herbicide use on three representative east-central corn belt farms.* M.M. Martin, J.R. Riepe, and J.R. Bahr. 1991. Weed Science 39:299-307.
- *Weed control in limited-tillage systems.* A.F.Wiese. 1985. Weed Science Society of America. Champaign, Illinois.

Effects of crop residue

Reducing preplant tillage changes the environment for weeds. These changes are most obvious in a no-till system and less in a chisel plow or disk system. As a consequence of plant residue from the previous crop not being buried, the soil becomes cooler and wetter, resulting in slower crop emergence and growth. With reduced tillage, weed seeds tend to remain at or near the soil surface. This coupled with the moist environment provided by the crop residues, favors weed seed germination and establishment (Yenish et al., 1992).

Research is underway to determine how the interaction of crop residues and herbicides is affecting weed control in conservation tillage systems. Crop residues can intercept soil-applied herbicides, altering the uniformity of the application reaching the soil surface. Buhler (1995) reports that up to 60% of the application may be intercepted by residue, but also that rainfall or irrigation may wash much of it off. Soybean residue is less problematic than residue from corn. Regardless of crop type, residue that has been evenly spread across the field during harvest causes fewer problems than strips of residue left behind the combine.

Weed species shifts

As preplant tillage decreases, weed populations change. Weed species with different life cycles have different requirements for growth and development. As the soil environment changes with reduced tillage, some species will flourish and some species will diminish. Summer annual weeds have become problems in modern agriculture because they are well adapted to tillage-based systems with high soil fertility, crops planted into rows and herbicide use (Buhler, 1995). Without tillage, other weed species become more prevalent.

Observations from farmers and researchers have indicated that as tillage decreases there is an increase in grassy weeds and a decrease in broadleaf weeds. Research has shown that these shifts in annual weed species with reduced tillage are mainly a function of weed seed size (Buhler and Daniel, 1988). Small cracks in the soil surface and under crop residue favor germination and establishment of small weed seed. Large weed seed on the soil surface does not establish as readily as small weed seed because the large seedling root (radical) has a hard time penetrating the small cracks. The large seed germinates on the soil surface where it can not get established and desiccates. Many broadleaf weeds such as velvetleaf and giant ragweed have relatively large weed seeds. While it is true that most of the grassy weeds have small seeds, broadleaf weeds such as common lambsquarters and redroot pigweed also have very small seeds. Buhler and Daniel report that populations of giant foxtail, common lambsquarters and redroot pigweed increase in conservation tillage systems, while velvetleaf tends to decrease. Figure 3.2 show this relationship between tillage, weed species, and establishment.

Switching to a conservation tillage system can increase the density and diversity of perennial weed populations due to decreased soil disruption if compensating control measures are not used (Buhler et al. 1994). Table 3.5 shows how perennial weed populations increased with no-till compared with moldboard plowing after four years. Perennial weed control in conservation tillage systems requires more planning than in a conventional system, plus the use of control practices such as a herbicide application or inter-row cultivation. Row crop cultivators designed for conservation tillage systems (discussed in the next chapter) are effective for annual weed control and suppression of perennials. However, they can not control pre-existing weeds in no-till systems, especially in no-till corn into alfalfa. No-till requires a preplant herbicide application to control existing vegetation. (One of the most effective herbicide combinations for controlling alfalfa is the fall application of a nonselective systemic herbicide such as glyphosate [Roundup] and a broadleaf growth regulator such as 2,4-D.)

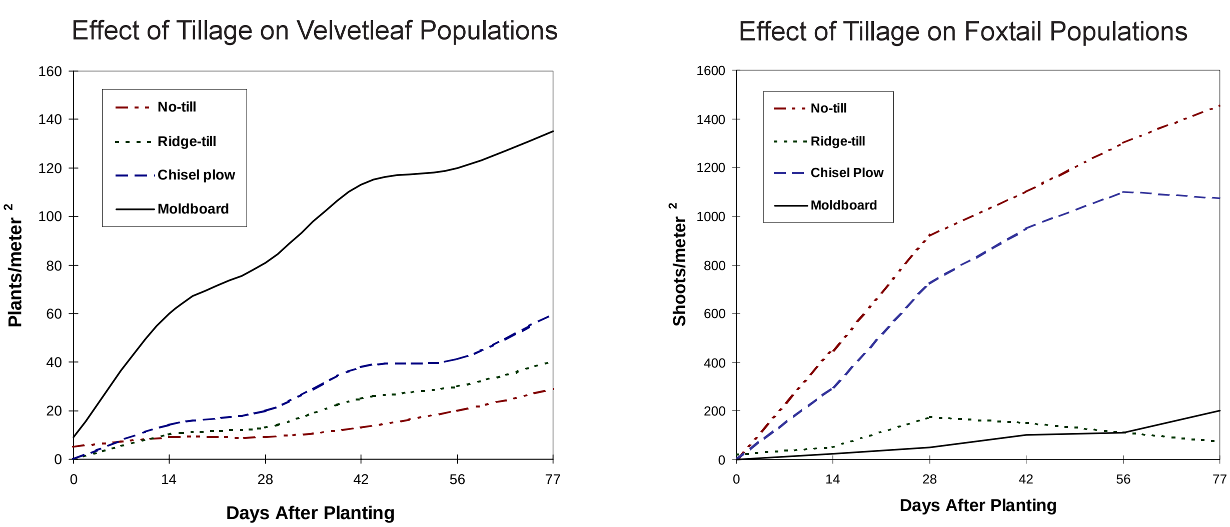
While the weeds in conservation tillage systems may be different from tillage-based systems, their control is not necessarily more difficult. Scouting for new weeds that will appear and planning for changes will help avoid weed problems when reducing tillage.

Selecting an appropriate crop variety

Too often a crop variety is selected based solely on previous yield performance. A number of other factors should also be investigated when selecting a crop variety. Maturity is one of the most important factors for weed management. Other important factors not specifically discussed here include disease resistance; tolerance to cold, pesticides, and other environmental stresses; and crop use. The better adapted a crop is to its environment, the better for crop competition.

Matching the correct hybrid maturity to local conditions is extremely important regardless of the crop grown. A shorter season hybrid will develop faster between emergence and silking and tasselling. This means canopy closure will occur sooner. If the maturity for a particular crop is too short for the growing season, the grower will experience losses in yield due to not taking full advantage of the length of the growing season. Conversely, a crop variety with a maturation period that is too long for the growing season may not establish itself early enough to compete against weeds. It also may not reach harvest maturity by the end of the growing season. When selecting a variety, it is important to get as

Figure 3.2. Effect of tillage on two common weed populations.



Adapted from Buhler and Daniel, 1988. Weed Science. Vol.36:642-647.

Table 3.5. Effect of 4 years of crop production under 3 tillage systems on perennial weeds.

	Tillage System		
Weed Species	Moldboard Plow	Chisel Plow	No Tillage
	weed shoots per acre		
Hemp Dogbane	890	940	1870
Field Bindweed	400	100	100
Yellow Nutsedge	40	60	435
Common Milkweed	0	3	35
Canada Thistle	0	3	5
Total Number	1330	1106	2443

Adapted from R. S. Fawcett, 1985. Weed control in conservation tillage. Iowa State Ext. No. Pm-1176.

much information about it as possible. Crop variety trial results from multiple locations and years should be consulted. Universities publish annual results of corn, soybean, small grain and alfalfa variety trials from a number of locations throughout the state.

Helpful references on crop variety selection.

These references can be obtained from any county Extension office or from Extension Publications, 630 W. Mifflin, Madison, Wisconsin 53703, phone 608-262-3346.

- *Wisconsin hybrid corn performance trials*. UW-Extension Bulletin A3653.
- *Selecting corn hybrids*. UW-Extension Bulletin A3265
- *Wisconsin soybean variety test results*. UW-Extension Bulletin. A3654.
- *Small grain varieties for grain and forage in Wisconsin*. UW-Extension Bulletin A3397.

Making appropriate planting decisions

Planting date

Proper planting date is essential for maximizing the benefit of crop competition against weeds. Early planting dates allow the crop to take full advantage of the growing season. University of Wisconsin research has indicated that corn planted after May 15 loses approximately one bushel of yield per acre per day delayed (Carter, 1987). Additionally, Oplinger and Albaugh (1996) report that soybeans planted from May 1 to June 24 lose approximately 0.5 bushel of yield per acre per day delay after May 1. On the other hand, a crop planted too early may not develop as quickly because cold soil conditions will not allow rapid germination of the crop seed. The result can be a crop that is less competitive against weeds that germinated before the crop. Table 3.6 provides a general guide to planting dates for several commonly grown crops. More detailed local information can be obtained from county Extension offices.

Planting depth

Planting depth plays an important role in the crop competition aspect of weed management. If the crop seed is planted too shallow it may not receive sufficient soil moisture for uniform germination and establishment. If seed is planted too deep, especially in fine textured soils, the environment may be too cold and wet, causing poor emergence and seed/seedling disease problems. It is critical for successful crop establishment and competition to vary planting depth by planting date and soil type. For example, corn planted April 20 in southern Wisconsin should probably be planted no deeper than 1 to 1.5 inches (Carter, 1984a). However, corn planted in early May might not germinate at this depth due to drier soil conditions. A planting depth of 1.5 to 2 inches may be more appropriate unless a fine-textured (clayey) soil dictates a shallower depth. A good rule to follow is plant to soil moisture and no deeper unless herbicide use requires a minimum planting depth.

Row spacing

Theoretically, planting crops in narrow rows improves yield because it allows the crop to capture more of the available light, water, and nutrients. While the yield advantage of narrow rows is important for farm profitability, an additional benefit of narrow rows is the increased competitive advantage against weeds. This is especially noticeable in drilled soybeans and small grains. Soybeans that have been drilled into 7 inch rows develop a canopy much quicker and yield better than soybeans planted into 30 inch rows (Oplinger and Philbrook, 1986). The more quickly developing canopy shades germinating weeds, making them less competitive (Beuerlein et al., 1996).

Narrow rows, however, only work to a certain point. Wisconsin research has shown a consistent yield increase for corn when planted in 30 inch rows versus 40 inch rows (Carter, 1984b). The same research saw inconsistent yield advantages when corn was planted in 30-inch rows versus 36-inch rows. Only a 1-2% yield increase was found when comparing 15 to 20-inch rows to 30-inch rows.

Plant population

The more crop plants established per acre, the less area for weeds. Increased densities of crop plants more effectively compete against weeds for water, light and nutrients. Once established, a vigorously growing, dense plant population is an effective means of weed management in combination with other cultural measures. (See discussion on cover crops.) For example, an established stand of alfalfa has very little annual weed pressure. If managed correctly, it also will have little perennial weed pressure.

Table 3.6. Suggested planting dates for five common Wisconsin crops.

	Suggested Planting Dates		
Crop	Southern	Central	Northern
Oats			
	April 15 - May 1	April 21 - May 7	May 1 - 15
Alfalfa			
spring seeding	April 15 - May 1	April 21 - May 7	May 1 - 15
fall seeding	Aug. 7 - 28	Aug. 1 - 15	July 24 - Aug. 7
Corn			
full season variety	April 20 - May 10	April 25 - May 10	May 1 - 15
shorter season variety	May 10 - 20	May 12 - 22	May 15 - 25
Soybean			
full season variety	May 1 - 15	May 10 - 20	————-
short season variety	May 10 - 20	May 15 - 20	May 15 - 30
Winter Wheat			
medium winter hardiness	Sept. 1 - 15	Aug. 25 - Sept. 15	Aug. 20 - Sept. 10
high winter hardiness	Sept. 15 - Oct. 10	Sept. 10 - Oct. 5	Sept.1 - 20

Source: Personal communication with J. Lauer, E. Oplinger and D. Undersander. 1997. UW - Madison, Dept. of Agronomy.

Helpful references on planting.

- *Optimum corn planting practices.* UW-Extension Bulletin A3264.
- *Soybean plant density for optimum productivity.* E.S. Oplinger and M.J. Albaugh.
- *Agronomy Advice* 27.424, February 1996.

Small grains such as oats and barley planted at two bushels per acre produce a very dense stand that can effectively compete against weeds. Corn will yield more at a density of 30,000 plants per acre than at lower densities in medium- and high-yielding environments (Carter, 1984a). Corn plants at the higher density shade out more weeds. Likewise soybean planted at 275,000 seeds per acre provides high yields and good competition against weeds (Oplinger and Gaska, 1996).

Proper plant populations often vary depending on the hybrid grown and crop use. Consult the hybrid literature as well as Extension information for proper plant populations.

Maintaining proper soil fertility

Proper nutrition increases a crop's ability to compete against weeds. Crop nutrients supplied by on-farm resources, such as manure and legumes, and/or purchased fertilizers should be applied in accordance with recommendations based on a soil analysis. Applications made in this manner supply the crop nutrients needed, help to keep the farm profitable, and reduce excess nutrients in the environment.

Appropriate nutrient management practices for crop production vary widely due to crop, topography, environment, and economic conditions. With the variety of factors to consider in crop fertility management, it is nearly impossible to recommend best management practices applicable to all Wisconsin farms. A number of options for improved nutrient management are available to growers and are briefly discussed in this section.

Routine soil tests and fertilizer recommendations

The most important consideration in sound nutrient management for crop production is the rate of application. Applying nutrients in excess of crop needs is unwise from both an environmental and economic viewpoint. However, soil nutrient levels that are inadequate to meet the requirements of a crop often result in lower yields and a less competitive crop. Soil testing is the key to accurately determining supplemental fertilizer requirements (Schulte, et al., 1985).

The University of Wisconsin soil testing system recommends soil nutrient applications at levels which, in combination with nutrients supplied by the soil, result in the best economic return for the grower. At "optimum" soil test levels, the recommended phosphorus (P) and potassium (K) additions are approximately equal to anticipated crop removal and are needed to maintain soil test levels in the optimum range.

An important step in the recommendation of appropriate P and K application rates is the determination of realistic yield goals. Yield goals must be achievable based on recent yield experience.

Using manure and legumes as a nutrient source

When determining supplemental fertilizer application rates, it is critical that nutrient contributions from manure, previous crops grown in the rotation, and land-applied organic wastes are credited. Using appropriate nutrient credits is particularly important in Wisconsin where legume crops and manure applications on cropland are common.

Manure is a valuable resource. Manure applications to cropland fields provide nutrients essential for crop growth; add organic matter to soil; and improve soil structure, tilth, and water holding capacity, all of which can favor rapid plant growth. Manure can supply crop nutrients as effectively as commercial fertilizers in amounts that can meet the total N and P requirements of corn.

Legume crops, such as alfalfa, clover, soybeans, and leguminous vegetables, have the ability to fix

atmospheric nitrogen and convert it to a plant-available form. When grown in a cropping rotation, some legumes can supply substantial amounts of nitrogen to a subsequent corn crop. For example, a fair stand of alfalfa can provide most, if not all, of the nitrogen needed for a corn crop following the alfalfa in a rotation. An efficient nutrient management program needs to consider the nitrogen contribution of a legume to the next crop.

When a field will be rotated from alfalfa to corn, the application of manure to the alfalfa field is not recommended. The primary reason is that the alfalfa stand will usually supply all the nitrogen that the corn requires. However, there is another reason. Research and farmer observations have shown that first year corn following alfalfa is relatively free of annual grassy weeds. Weed seed that may be contained in manure can introduce a weed into a relatively weed free field. Simply stated, the amount of weed seed contained in manure is directly related to the amount of weed seed in the feed. From both nutrient and weed management aspects, the application of manure to an old alfalfa field is not a recommended practice.

Starter fertilizer

Starter fertilizer can help crops get an early competitive edge on weeds. The first plant that obtains light, water and nutrients from a site will have a competitive advantage over plants that develop later. One plant's early growth can suppress the growth of later emerging plants by developing a shading canopy and/or an extensive root system.

A small amount of starter fertilizer is recommended for corn planted into soils that are slow to warm in the spring. For corn grown on medium-to-fine textured soils, a minimum application of 10 pounds per acre of nitrogen, 20 pounds per acre of phosphorus and 20 pounds per acre of potassium is recommended as a starter fertilizer at planting for rapid crop development.

Helpful references on soil fertility.

These references can be obtained from any county Extension office or from Extension Publications, 630 W. Mifflin, Madison, Wisconsin 53703, phone 608-262-3346.

- *Nutrient management: Practices for Wisconsin corn production and water quality protection*. UW-Extension Bulletin A3557.
- *Using legumes as a nitrogen source*. UW-Extension Bulletin A3517.
- *Soil nitrate tests for Wisconsin cropping systems*. UW-Extension Bulletin A3624.
- *Soil test recommendations for field, vegetable and fruit crops*. UW-Extension Bulletin A2809.
- *Guidelines for applying manure to cropland and pastures in Wisconsin*. UW-Extension. Bulletin A3392.
- *Sampling Soils for Testing*. UW-Extension Bulletin A2100.

Influence of nitrogen on weed control

Weeds can be more competitive with crop plants at high soil fertility levels and often accumulate higher concentrations of nitrogen, phosphorous, potassium, calcium and magnesium than many crop plants (Di Tomaso, 1995). Some weed species, such as redroot pigweed, are nitrate accumulators. Certain weed species even prefer the nitrate form of nitrogen over the ammonium form of nitrogen. For example, Teyker et al. (1991) reported a differential growth response in corn and redroot pigweed to nitrate and ammonium forms of nitrogen. Corn grew the same regardless of what form of nitrogen was applied. In contrast, redroot pigweed showed a dramatic reduction in shoot dry weight (75%), and total N accumulation (57%) when ammonium was the main form of nitrogen. The authors suggest that increasing the amount of ammonium may assist in managing known nitrate accumulators like redroot pigweed.

Earlier research done by Staniforth (1961) reported that as nitrogen rates were increased from 0 to 140 pounds per acre, the competitive effects of yellow foxtail on corn grain yield decreased. However, weeds can also respond to increases in nitrogen levels - in the same research, foxtail biomass doubled with the increase in nitrogen. This indicates that proper nitrogen rates may decrease the competitive effects of weeds by improving the competitive nature of the crop, rather than having a detrimental effect on the weeds themselves.

Together, the research reports from Teyker and Staniforth suggest that the proper rate of nitrogen applied in the ammonium form may increase crop competition and decrease weed competition in corn production for certain species of weeds. In any case, proper rates of nitrogen are always recommended.

Summary

Cover crops can suppress weed growth. A number of cultural practices can increase crop competition against weeds. These are fundamental practices that must be done accurately and at the appropriate time. Ignoring these crop production practices will have a direct impact on weed management.

Preventative practices will keep a weed species from spreading. Crop rotation creates an unfavorable environment for any one weed species to become dominant. Timely seedbed preparation provides the crop with an early competitive start. Changes in weed populations brought on by changes in preplant tillage operations require changes in management strategies. Selecting a suitable crop variety, planting it at the proper rate, depth and row spacing will improve the crop's performance against weed competition. Finally, sound nutrient management will provide the nutrients the crop needs to be competitive and profitable.

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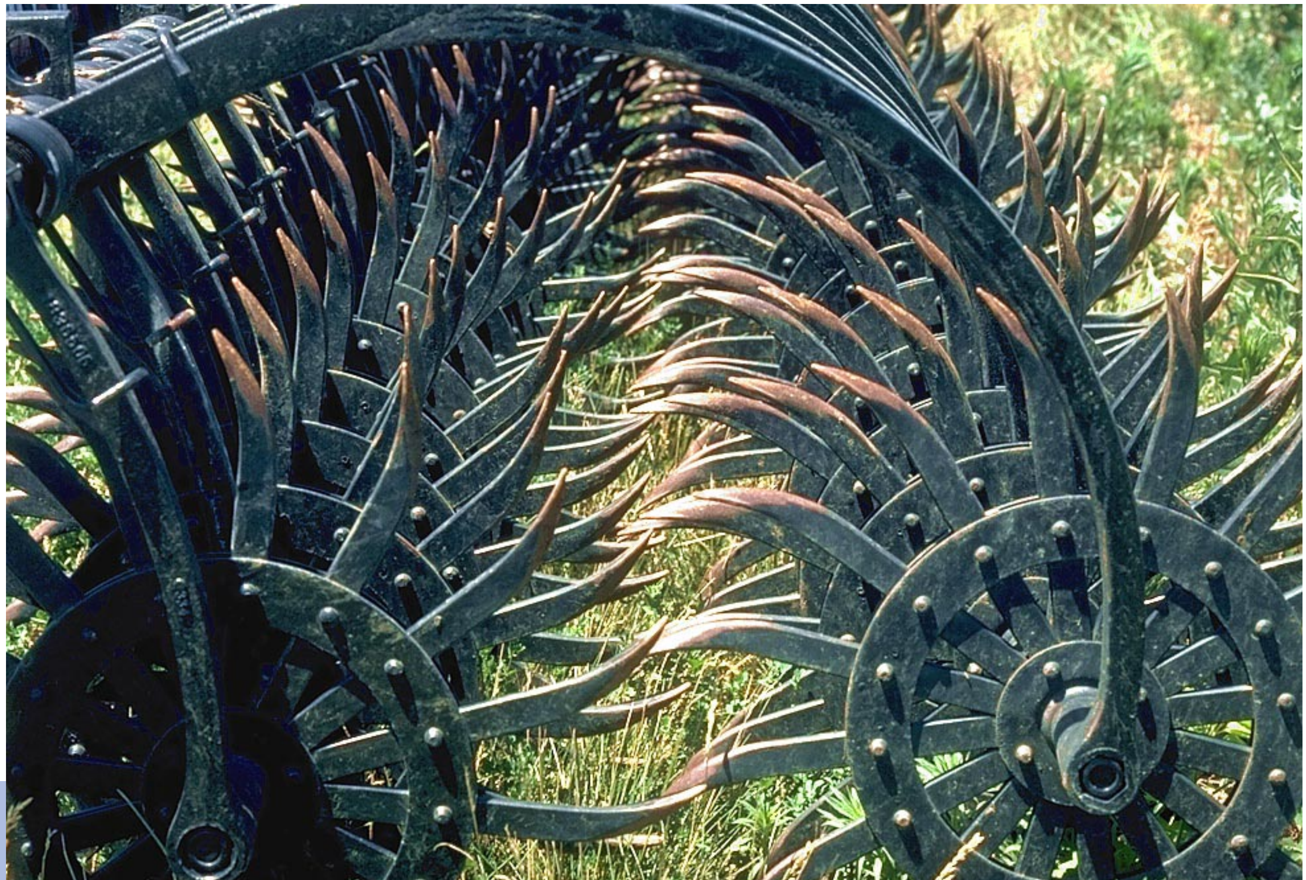


4 Mechanical Weed Management Strategies

Consistent, long-term weed management in agricultural production often requires a comprehensive approach integrating mechanical practices as well as cultural and chemical ones. Primary and secondary tillage operations, already discussed in Chapter 3, are mechanical methods of weed control. These operations uproot, chop off, or bury existing vegetation when preparing the seedbed. Practices such as mowing and flame weeding are also included in the mechanical category. Usually, however, we think of post-plant tillage operations as providing mechanical weed control.

Common mechanical weed control practices are using a spike tooth harrow, rod weeder or rotary hoe after planting but before crop emergence, or a rotary hoe or row-crop cultivator after crop emergence. Again, these implements remove germinating and small weed seedlings by cutting, burying or dislodging their root system. The discussion in this chapter focuses on rotary hoeing and inter-row, or between-row, cultivation. These are the mechanical weed management practices used most often in corn and soybeans.

Why consider mechanical weed management?

There are many reasons to consider a mechanical component in an integrated weed management program. Label recommendations for some preemergence herbicides suggest using a rotary hoe to enhance the product's activity in dry soil conditions. Others recommend cultivation to supplement control of difficult weeds.

As more herbicides with identical modes of action are used each year in corn-soybean rotations, the potential development of herbicide resistant weeds becomes a concern. To combat herbicide resistance, multiple weed management strategies will be required. Cultivation and rotary hoeing provide an additional mechanism of control. Thus, a well-managed mechanical component can help keep a farmer's chemical tools effective for the long term.

Also, many growers believe economic yield improvements will occur with cultivation even when weeds are fully controlled by herbicides. This is probably due to cultivation improving soil aeration and water infiltration.

Finally, in some cases, mechanical methods can replace some or all of the chemical weed control inputs. This has potential to benefit both the environment and farm profitability. Relying less on herbicides, however, requires above-average management of cultivation timing, cultivator adjustment, speed of operation and, to a lesser extent, cultivator selection.

For all mechanical operations, farmers' decisions and management skills are critical. There are no prescriptions for the number of passes with each tool or whether each tool needs to be used. Much will depend on the spectrum of weeds and weed seeds present, the crop rotation, extent of tillage, and soil and weather conditions.

Rotary hoeing

Rotary hoes are frequently used to break soil surface crusts formed by rainfall on newly prepared seedbeds. However, many corn and soybean growers in the Midwest also rely on rotary hoeing as an integral part of their weed management program. In tillage-based crop production systems, a rotary hoe can be used for weed control after planting but before crop plants are large enough for between-row cultivation. The shallow penetration of the hoe teeth dislodges germinating weed seeds at or just below the soil surface and above where the crop seed takes root.

A rotary hoe consists of ground-driven wheels, each with 16 curved spikes in a shape resembling spiders. On newer models, each spider-like wheel is attached to a spring-loaded arm mounted to a tool bar. The spider-wheels are approximately 1.5 ft in diameter and are placed approximately 5 inches apart. The wheels are often mounted in a staggered, paired arrangement for greater clearance between wheels. This allows greater flow-through of crop residue. The picture at the opening of this chapter is a close-up of a rotary hoe.

The ends of each spider are spoon-shaped. While penetrating the soil surface, the spoons stir the soil and flick out tiny germinating weeds and seeds. Only small-seeded weeds germinating in the top 1-2 inches will be dislodged. Spoon wear is a factor in effectiveness of penetration and weeding. The hoe must be operated at relatively high forward speeds of 6 to 10 miles per hour.

Potential for stand reduction or damage with rotary hoeing

Research trials in Wisconsin have shown minor stand reduction from rotary hoeing. Two rotary hoeings reduced corn plant populations an average of only 5% when compared to no rotary hoeing across three planting dates in 1990 and 1991 (Mulder and Doll, 1992). There were no distinct differences in stand loss between planting dates, hoe timing and first and second hoeings. Some of the stand loss occurred from corn seed removal by the early hoeing. A uniform planting depth of 1.5 to 2 inches would have minimized this loss. Some loss also resulted from burying emerged plants at the second hoeing.

Increases in seeding rate are probably not necessary if only rotary hoeing once. However, when relying on the rotary hoe as a herbicide replacement for early season weed control, more than one pass may be necessary. In this case, it may be advisable to increase seeding rate 5 to 10 percent for corn or soybeans.

It is a good idea to check closely what the hoe is doing in the first few passes across the field. If there appears to be substantial seed displacement or uprooting or covering of seedlings, it may be necessary to adjust the hoe, reduce speed or quit altogether.

Rotary hoeing soybeans should be avoided when plants are in the "crook" stage to avoid stem breakage. Also, soybeans are slightly more vulnerable to population reduction from rotary hoeing when drilling has resulted in variable seeding depth.

Rotary hoes less effective in reduced tillage systems

Rotary hoes work best in tillage-based production systems. Some models mount the spider wheels on individual spring-loaded arms and every-other arm is extended further back to allow better flow-through of residue and prevent plugging. However, old corn

A rotary hoe stirs the soil and flicks out tiny germinating weeds and seeds.

Table 4.1. Control of broadleaf weed species prior to inter-row cultivation in a chisel plow and finishing disk tillage system at Arlington, Wisconsin, 1989-90.

Preemergence treatment	Herbicide rate	-- Broadleaf weed control -- 1989	1990
	—— lb/a ——	- - - - - weed control, % - - - - -	
Rotary hoe (3x)	-	64	36
Atrazine	1.0	76	96
Cyanazine	1.7	78	92
Atrazine +	1.6		
metolachlor	2.0	94	99

Adapted from D. D. Buhler, J. D. Doll, R. T. Proost and M. R. Visocky. 1995. Agronomy J. 87:507-512.

roots can still be a problem unless fields are tilled. Rotary hoes are not effective in no-till or when surface residue is greater than 60 %.

In ridge-till systems, however, rotary hoes work well to control weeds in the row. One or two passes supplement or may eliminate the need for banded herbicides (Grisso and Schuler, 1992).

Weed control effectiveness varies

Two University of Wisconsin integrated weed management experiments provide assessments of rotary hoe effectiveness. The first, a 1989-90 study in continuous row-crops, compared three rotary hoe passes (no herbicides) with three different preemergence herbicide programs for controlling early season weeds (Buhler, et al., 1995). Pre-cultivation weed control in the rotary hoe system ranged from 36 to 64% (compared to untreated control plots). In contrast, preemergence herbicides, including atrazine alone at a reduced rate, provided 76 to 99% control (Table 4.1). In addition, the study's authors report that when there was at least one cultivation, rotary hoeing did not improve later-season weed control compared to no preemergence treatment at all. Weed pressure was mainly from annual broadleaves. Rotary hoeing was most effective in 1989 when dry soil conditions prevented re-establishment of weeds dislodged by hoeing.

The second study's results were more positive regarding the effectiveness of the rotary hoe as a weed control tool. Rotary hoeing was evaluated as a compliment to herbicide applications, as well as by itself, at the Lakeland Agricultural Complex (Walworth County Farm) and the Arlington experiment station in 1990 and 1991 (Mulder and Doll, 1992). The herbicide Bicep was applied both broadcast and in 15-inch bands over the rows, both at normal and one-half rates. In 1991, reducing banded and broadcast herbicide rates significantly decreased pre-cultivation weed control where rotary hoeing was not used. However, this decrease was eliminated by only one timely rotary hoeing (Table 4.2). In addition, this second study found that three rotary hoeings and two cultivations provided weed control equal to that with full rate broadcast herbicide alone in three of four trials (1990 and 1991 at Lakeland and 1991 at Arlington) and equivalent corn yields in all four trials.

The effect of planting dates on weed control was examined at Arlington for these trials. In both years, the rotary hoe controlled in-row weeds better when planting was delayed from April 25 to May 5. With the later planting date, more of the weeds had germinated, and were therefore killed, at the time of rotary hoeing. Also, the warmer, drier soil conditions later

Table 4.2. Visual in-row weed control ratings taken before first row cultivation with conventional and reduced herbicide rates, rotary hoeing, and combinations of herbicide and rotary hoeing.

Weed control system		In-row weed control rating[1]			
		Arlington Research Station		Lakeland Ag. Complex	
Rotary hoe[2]	Herbicide[3]	1990	1991	1990	1991
No. of times		%			
0	Normal rate-broadcast	98	84	92	91
0	Half- rate broadcast	95	76	91	78
1	Half- rate broadcast	97	86	91	94
1	None	26	74	75	69
2	None	29	83	89	83
3	None	78	83	92	93

[1] No weed control = 0 %; no weeds = 100%.
[2] Rotary hoeing at 7, 14 and 21 days after planting in 1990 and at corn heights of 1, 2 and 5 inches in 1991.
[3] Herbicide is Bicep; normal broadcast herbicide rate is 1.6 lb/acre atrazine and 2.0 lb/acre metolachlor.

Adapted from: T. A. Mulder and J. D. Doll. 1992. *Wisconsin Integrated Cropping Systems Trial, Second Report.* UW-Madison.

in the season lead to better hoe action and increased corn competitiveness. Delaying planting until May 15 further improved weed control, but resulted in an economic yield loss.

Results from this research suggest that if corn is planted from May 5 through the 15, and growing conditions are favorable for rapid crop establishment, effective weed control can be achieved with two rotary hoeings and two cultivations without herbicides. However, economic yield losses are likely from late planting. Premium prices paid for organically produced crops may offset yield losses associated with delayed planting. Earlier planting and some in-row herbicide use will likely be necessary to avoid economically damaging weed growth and yield loss.

Timing rotary hoeing

Timing is critical for success with rotary hoeing. If it is done too long after the last tillage, weeds will have grown too large to be effectively dislodged by the hoe. If done too soon after planting, weeds may not have germinated, resulting in ineffective hoeing.

In the past, some recommended timing the first rotary hoe operation approximately 5 to 7 days after planting and the second rotary hoeing 7 to 10 days later. This timing is not accurate, especially with early planting dates and in years when cool soil temperatures delay weed seed germination.

Rotary hoeing is better timed in relation to actual weed and/or crop growth stages. Effectiveness is maximized when germinating weed seeds and roots show white thread-like roots. Another good approach is to perform rotary hoe operations when corn has germinated but is still about an inch below the soil surface and then again when it is 1-2 inches above the surface (Mulder and Doll, 1992).

Inter-row cultivation

Inter-row cultivation is also known by the terms *between-row*, *row,* and *row-crop cultivation*. Several types of row-crop cultivators, including C-shank, S-tine (Danish tine, spring tine or vibrating shank), conservation tillage, or rolling (rotary) can be used for this purpose. The main purpose of the row crop cultivator is to uproot, cut off and bury small weeds between crop rows. Cultivation can also create a "dry mulch" in the top of the soil where seeds cannot germinate due to lack of moisture. Small weeds within the row can be buried by the cultivator without damaging crop plants if soil is thrown carefully into the row. However, if care is not taken, the crop plant can also be buried. Cultivation alone may not provide adequate weed control; additional cultural and/or chemical practices are often required to suppress in-row weeds to avoid economically damaging yield loss.

Timing cultivation

As with rotary hoeing, timing a cultivation properly is critical to its success. It must be done before weeds are too large to be effectively dislodged, buried and/or cut down. Cultivation is timed according to stages of weed and crop growth. Cultivating before the crop reaches 3 inches in height, however, is difficult. Small plants are easily buried by soil clods or plant residue stirred-up by the cultivator. Corn may need to be as high as 6 inches depending on the type of cultivator and whether protective shields are used. Unfortunately, the best time for first cultivation may conflict with the first hay harvest or spring rains.

A first-pass with a cultivator when the crop is about 3 to 6 inches high requires relatively slow travel speeds of around 3 to 5 miles per hour to avoid covering small plants. Higher speeds are possible for subsequent passes. However, cultivators must still be operated with care at later stages of crop development to avoid pruning roots.

Cultivator adjustment

Cultivator adjustment is as important as timing. The cultivator's points, shovels, sweeps, spiders, disk hillers and shields must be set with the right depth and spacing. These parts should also be checked for wear and replaced if necessary. Depth of cultivation is usually about 2 inches for the first pass, but will depend on specific conditions. Greater depth or downward pressure may be needed in some rows to overcome soil compaction from tractor tires.

Accurate spacing of the cultivator tools is critical for cultivating as much area between each row as possible, as well as for throwing the desired amount of soil into the row. Care must be taken that crop roots are not being damaged, especially at later stages of growth. Cultivation can reduce yields by physically damaging shoots or roots. The cultivator should penetrate enough to cut off certain weeds, but not deep enough to cut the crop roots.

Cultivator types

Proper cultivation timing and adjustment of cultivators are generally more important for weed control than cultivator design. Probably the biggest differences between types of cultivators is the depth and speed at which they are able to operate, along with their ability to handle the increased surface residue and soil conditions associated with conservation tillage systems, particularly no-till.

Most cultivator designs available today will perform well in tillage-based production systems. Cultivating in no-till, however, requires specialized design features. An individual grower's experience with different types of cultivators and cultivator tools will play a role in selection. However, there are some basic differences in cultivators that should be considered when developing the mechanical component of an integrated weed management program.

■ ***C-shank and solid shank cultivators***

There are many variations of shank-type cultivators. The traditional design consists of frame-mounted, C-shaped shanks with soil-penetrating tillage points attached. The C-shape of the flat steel shank acts like a spring, keeping pressure on the point and allowing vibration to enhance soil shattering. Traditional designs include three to five C-shanks, using 2 inch "straight-points" or "shovels" for each between-row unit. Some newer models mount the C-shanks in gang assemblies connected to the tool bar with a parallel linkage and may also use additional down-pressure springs.

As the number and position of shanks and the type of points can be adjusted, C-shank cultivators offer good flexibility. C-shank cultivators can work with reduced tillage, but if they have more than one

C-shanks in gang assemblies connected to the tool bar.

shank per row, they are susceptible to plugging when the previous crop was corn for grain. Plugging is not a problem when the previous crop was corn silage, alfalfa, wheat or soybeans. Models designed for conservation tillage use only one to three shanks with wider "sweep" and "half-sweep" points. This allows greater flow-through of crop residue. Shanks used on these models are more rigid or are solid. (See "Conservation tillage cultivators" below.)

Most of the traditional cultivators used for corn and other row crops in the Midwest are rear-mounted shank cultivators. Front-mounted C-shank cultivators, mounted ahead of the tractor, are available but are less common. Center-mounted C-shank cultivators, mounted between the front and rear wheels, were popular for the early row-crop tractors of the 1940s and 1950s.

Contemporary center-mounted models are available. They are slightly more complicated and time consuming to put on and adjust, but permit cultivation closer to the row than front or rear-mounted cultivators. Center-mounted cultivators are easily seen from the driver's seat and are less responsive to steering deviations, and subsequent corrections, than front or rear mounted cultivators. This helps to reduce incidence of "cultivator blight".

Shank cultivators, outfitted with points or shovels, will enable deeper, more aggressive cultivation than S-tine or rolling cultivators (discussed below). Cultivation 2 to 4 inches deep is comparatively easy. Shovels can be adjusted for moving soil into the row at first or second cultivation. Shank cultivators equipped with sweeps will slice and lift the upper soil surface, pushing soil to the sides. Additional soil can be moved into the row with weeding-disk or disk-hiller attachments.

The S-tine (pictured above) gives more vibrating action than the C-shank.

■ *S-tine (Danish tine, spring tine or vibrating shank) cultivators*

The S-tine cultivator uses long, vibrating S-shaped tines with duck-feet points at the end. There are usually five tines per row unit. The S-tine gives more vibrating action than the C-shank. The vibration stirs and loosens soil over a wide area between rows. This cultivator operates at shallow depths and can be pulled at slightly higher speeds than a C-shank cultivator. It leaves the cultivated area level and moves less soil into the row. It is less effective than other cultivators on weeds more than 2 inches tall. It is not well adapted to heavy residue conditions such as those with no-till corn following corn, but can be used in reduced tillage fields where crop residue levels are lower.

■ *Rolling (rotary) cultivators*

The rolling cultivator uses sets of 3 slicer-tine, ground-driven spider wheels set on a common axle to form a gang. The gangs run at a slight, adjustable angle along each side of the row. The tines are twisted and beveled to slice and lift soil. For good mixing, they must be operated at speeds of 5 to 7 miles per hour (Springman et al., 1989). The gangs can be angled to throw soil away from the row at first cultivation and back toward the row at a second pass when the corn is taller. Thus, the rolling cultivator can be used for ridging or hilling.

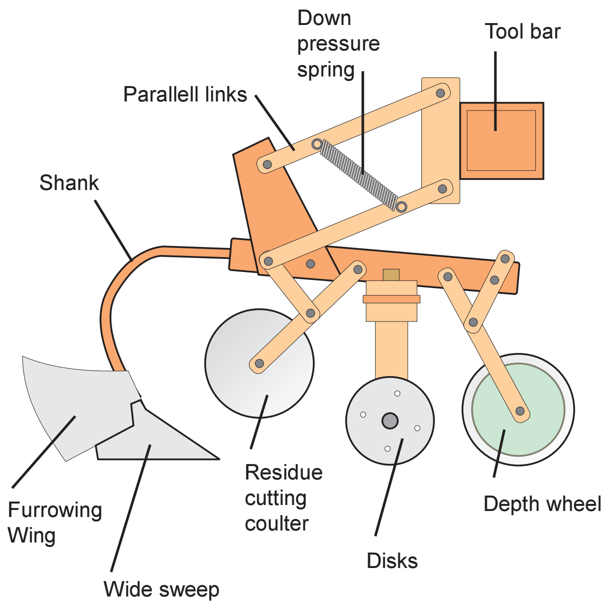
The rolling cultivator can be operated at high speeds and can be adjusted to leave the soil surface level. Adjusting the rolling cultivator is more difficult than for other types of cultivators. Its tillage is relatively shallow, and it cannot handle more than a 50% residue cover without clogging. The rolling cultivator is best adapted to reduced tillage fields with light-to-moderate residue levels.

■ *Conservation tillage cultivators*

Conservation tillage cultivators are designed to handle a firmer soil surface and increased crop residue associated with conservation tillage systems, especially no-till. Most are modified versions of the shank cultivators described above. Rather than 3 to 5 shanks per row, these cultivators have a single heavy-duty shank per row unit. This allows easier passage of surface residue without plugging.

A single V-shaped sweep, 12 to 20 inches wide, serves as the working point. The sweep slices just below the soil surface, cutting off weeds and moving

Figure 4.1. Components of a conservation tillage cultivator.



Source: R.D. Grisso and R.T. Schuler, 1992. Conservation Tillage Systems and Equipment. Midwest Plan Service. Ames, Iowa.

soil toward the row. Sweeps disturb and bury less surface residue than other cultivator points. A coulter normally runs ahead of the sweep to break the soil surface and cut through surface residue. Conservation cultivators generally have a heavier construction (shanks, frame and tool bar) than conventional models and may have down-pressure springs to increase soil penetration (Figure 4.1).

Disks are often used on these cultivators to control weeds close to the row. Such disks, sometimes referred to as “disk hillers”, “barring-off disks” or “weeding disks”, are the workhorses of a ridge-till system. Generally, they would be turned to move soil away from the crop row at first cultivation and then toward the row at subsequent passes (Grisso and Schuler 1992).

Performance of different cultivator types similar

University of Wisconsin trials in 1990 and 1991 compared cultivators from each of the four types described above: S-tine (Danish tine), C-shank, conservation tillage, and rolling (Lilliston) (Mulder and Doll, 1994). At the U.W. experiment station at Arlington, each cultivator was used when corn was 5 inches tall and again at a height of 20 inches. The cultivators were set at a 2-inch depth for the first cultivation. The C-shank and rolling cultivators were lowered to a 3-inch depth on the second cultivation. In-row and between-row weed densities, plant population and corn yield were compared for each cultivator type.

In these trials, the first cultivation reduced corn stand by an average of 1.2% and the second cultivation reduced it by an additional 2.5% (Table 4.3). Because the rolling cultivator moved soil away from the corn plants at first cultivation, it affected the stand less than the others. However, the rolling cultivator also was slightly less effective than the others at controlling in-row weeds at first cultivation (Table 4.4). On average, yields were similar for all cultivators.

Cultivator guidance systems may make cultivation easier

Inter-row cultivation is often a tedious, tiring and time-consuming task. Relatively slow speeds and careful attention to following crop rows are required to avoid damaging the crop. Large cultivators, six to twelve or more rows wide, help to cover more acres per hour, but increase the potential for cultivator damage. Larger cultivators can be more difficult to control and keep adjusted under variable field conditions. Furthermore, each time the operator deviates from course, a greater number of rows will be affected.

Popular cultivator shovels, points and sweeps

1½-2” Reversible shovel or straight point: Used on C-shank and S-tine cultivators to stir soil, break surface crust, and dig out small weeds.

Spear points: Used on C-shank cultivators to scour through soil, uprooting and cutting off weeds. They can be positioned to move soil toward the row.

Duckfoot sweep: Used on middle shanks of S-tine cultivators to slice under soil surface, cover more area, and bury less residue than straight points.

Conservation sweep: Used on single shank conservation tillage cultivators to penetrate hard soil surfaces and scour beneath the surface, cutting off and uprooting weeds while leaving surface relatively undisturbed.

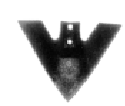


Table 4.3. Comparison of corn population reduction caused by cultivation with four types of row-crop cultivators.

	1st row cultivation[1]			2nd row cultivation[2]		
	1990	1991	Avg.	1990	1991	Avg.
	% population reduction					
S-tine	0.8	3.7	2.2	3.9	0.5	2.2
Conservation tillage	2.3	0.2	1.2	3.3	2.0	2.7
Rolling	-0.5[3]	-0.2[3]	-0.4	3.2	2.3	2.7
C-shank	1.2	2.3	1.7	3.8	1.1	2.5
LSD (0.05)	1.8	2.5	1.5	NS	1.7	NS

[1] Based on plant counts taken prior to second cultivation, compared with counts prior to first cultivation.
[2] Based on plant counts taken after corn tasseling, compared with counts taken prior to second cultivation.
[3] Some plants emerged after the first cultivation.

Source: T.A. Mulder and J.D. Doll. 1994. J. Prod. Ag. 7:258.

Table 4.4. Visual in-row weed control ratings at canopy and corn yield for four row-crop cultivator types in 1990 and 1991*.

	In-row weed control			Corn yield		
Cultivator type	1990	1991	Ave	1990	1991	Ave
	% weed control			*bu/a*		
S-tine	89	89	89	163	182	172
Conservation tillage	91	91	91	157	191	174
Rolling	85	90	87	158	197	177
C-Shank	92	89	90	162	185	173

* Data are averages from two different methods of early-season weed control: (a) 2 rotary hoeings or (b) 10-inch over-the-row herbicide band of 1.6 lb/a atrazine + 2 lb/a metolachlor applied pre-emergence.

Adapted from T. A. Mulder and J. D. Doll. 1994. J Prod Ag. 7:258.

Cultivator guidance systems assist cultivation by keeping the cultivator on track. They may be especially helpful when cultivating row crops grown on contour strips. Mechanical guidance tools such as cone guide-wheels and sled-type shoes have been used to guide cultivators in cotton and vegetable crops. For corn and row-planted soybeans, electro-hydraulic guidance systems for rear-mounted cultivators are better suited (Figure 4.2.).

Electro-hydraulic guidance systems generally consist of three main components:

- a three-point mounted, quick-coupling hitch adapter that either moves from side-to-side or pivots;
- row-sensing wands or probes that keep track of the crop rows; and
- an electronic controller that communicates the signals from the wands to the hydraulically adjusted hitch.

Row-sensing wands that keep track of the crop rows.

If the operator deviates from course, the wands will be pushed against the rows sending a signal to the hitch, via the controller, to adjust proportionally to keep the cultivator between the rows. Electro-hydraulic guidance systems are capable of adjusting approximately 4.5 to 10 inches in either direction from center.

High residue may pose a challenge for the wand-driven systems. Last year's corn stalks may be mistaken for this year's row, resulting in misdirection. Some models have been adapted to hug closely to each side of a single row, rather than brushing along between two rows, to minimize this problem. Some manufacturers offer alternatives to the wands. One example is a "marker ball" sensing probe designed to follow a guidance furrow left by a marking device attached to the planter. Other sensing devices used with electronic controllers include guide-wheels or ridge-sleds used for crops grown on ridges.

The biggest reported advantages to guidance systems are increased cultivation speed, reduced operator fatigue and decreased crop damage. These advantages may enable the farmer to cover significantly more acreage with cultivation. Thus, reduced labor time and the ability to reduce herbicide rates on more acres are also potential advantages. Economic justification for purchasing a guidance system relies, in part, on the value the operator places on comfort and reduced stress since electro-hydraulic guidance systems cost from $4,000 to $10,000.

Potential for non-weed control yield benefits from cultivation

Research on the benefits of cultivation beyond weed control have had mixed results. One study showed that inter-row cultivation was economically advantageous even when weeds were fully controlled with herbicides (Siemans and McGlamery, 1985). Research conducted from 1982 to 1984 at the University of Illinois showed a corn yield increase of 10 to 20 bushels per acre associated with cultivation on a clay loam soil (Table 4.5). Similarly, soybean yields were increased 7 bushels per acre by cultivation. The multi-year trials were conducted over four different tillage systems that ranged from moldboard plow to no-till. The highest cultivation-based increases were observed in reduced till (chisel and disk) and no-till plots. Improved soil aeration, water infiltration, and moisture conservation are thought to cause the yield boost from cultivation (Johnson, 1985).

University of Wisconsin research has not shown the same benefits of cultivation on corn yield. In two multi-year experiments, yields were not increased by cultivation where full rates of atrazine and metolachlor were applied (Buhler et al., 1995; Mulder and Doll, 1993).

Figure 4.2. Cultivator guidance systems assist cultivation by keeping the cultivator traveling parallel with the row, while allowing lateral movement of the tractor.

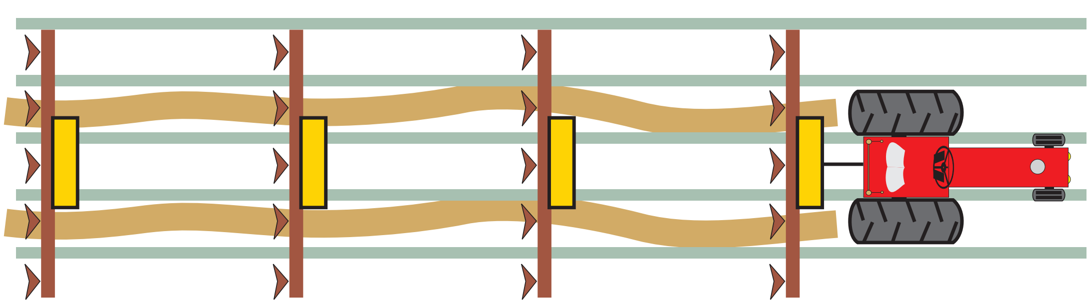


Table 4.5. Effect of cultivation on central Illinois corn and soybean yields when grown under different tillage and crop production systems.

	Moldboard plow	Chisel plow	Disk	No tillage	Average
	- - - - - - - - -	- - - - - - - - -	bu/a	- - - - - - - - -	- - - - - - - - -
Continuous corn, Thorp soil[1]					
Not cultivated	154	124	128	103	127
Cultivated	162	148	148	110	142
Continuous corn, Drummer soil[1]					
Not cultivated	144	130	125	80	120
Cultivated	155	140	144	119	140
Corn after soybeans, Drummer soil[2]					
Not cultivated	160	150	153	146	152
Cultivated	171	160	159	160	162
Soybeans after corn, Drummer soil[2]					
Not cultivated	45	40	38	40	41
Cultivated	52	48	46	48	48

[1] Averages for years 1982 - 1984.
[2] Averages for years 1983 - 1984.

Source: J. C. Siemens and M. D. McGlamery. 1985. Proc. Am.Soc. Agric. Eng. ASAE paper 85-1010.

Cultivation and soil erosion

Row cultivation is a very effective weed management method, but many have questioned whether it also increases soil erosion. A study conducted by Siemens at the University of Illinois suggests that if done on the contour, cultivation may actually decrease soil erosion due to increased infiltration and delayed run-off (Johnson, 1985). Two fields, one chisel plowed and the other no-till, with slopes of 3 to 5%, were subjected to an intense artificial rainfall. Under the conditions of this study, the chisel plowed field with row cultivation on the contour lost approximately 1 ton of soil per acre after 3 inches of rainfall, while the uncultivated field lost more than 2.5 tons of soil per acre at the same rainfall intensity. The cultivated part of the no-till field also had less soil erosion than where it was uncultivated, but the difference was less dramatic, probably because the cultivation was done up and down slope rather than on the contour.

Economics of mechanical weed management

What is the value of the mechanical component of an integrated weed management program? Obviously, this is the central question most farmers need to answer when developing the mechanical component of their own weed management program.

The net benefit associated with cultivating and/or rotary hoeing is determined by comparing the costs of these operations with the resulting changes in returns. Costs of mechanical weed control are determined by the cost of both owning and operating the equipment. Changes in returns can take the form of increased or decreased yields and/or reduced herbicide costs.

The following examples of equipment ownership and operating cost computations use procedures and cost estimates developed by Frank and Shuler (1990).

Equipment ownership costs

Annual equipment ownership costs, including depreciation, are determined by the purchase price, the number of years that the cultivator and/or rotary hoe will be used and the interest rate applied to the money invested in the equipment throughout its ownership. If the equipment is insured, or is subject to any personal property tax, these amounts are also included in the annual ownership cost.

Example:

- *A new six-row, no-till cultivator purchased for $6,000 with an expected useful life of seven years and a relevant interest rate of 8% costs approximately $900 per year to own.*

Fixed costs are a function of ownership and will be incurred regardless of use. Thus, per acre cost will be lower when this fixed cost is spread over more acres.

Example:

- *If the cultivator described above is used on 100 acres per year, the annual fixed cost per acre is $9.00. If, however, the cultivator works on 300 acres, the estimated annual fixed cost is only $3.00 per acre.*

Equipment operating costs

Annual operating costs include labor, fuel, oil, repairs and maintenance for tractors and implements used in the mechanical weed management program.

Example:

- *Assume a two-cultivation system with the no-till cultivator. A first pass (at corn heights of 3 to 6 inches) is performed at a speed of 3 miles per hour, and a second pass is performed at 4 miles per hour. This would be equivalent to 11 minutes per acre cultivated in the first pass and 8 minutes per acre cultivated in the second. An additional time of 25% can be added for hook-up, re-fueling, inter-field travel and turning at row-ends (Doll et al., 1992). Thus, 24 minutes per acre (4 acres per hour for the first cultivation and 6 acres per hour for the second cultivation) at $10 per hour for labor equals $4 per acre in labor for the two cultivations.*
- *Assume a 90 horsepower diesel tractor pulls the 6-row, 30-inch cultivator and uses four gallons of fuel per hour. Along with oil, this costs $1.60 per acre for the two cultivations.*

Repair and maintenance costs are estimated as a function of the age of the machine, the number of acres for which it is used each year, and its original purchase cost.

Example:

- *The estimated seven-year average repair and maintenance cost for the no-till cultivator is $.40 per acre for 100 acres cultivated twice, but increases to $.80 per acre for 300 acres cultivated twice.*

Total cost estimates for the 100-acre and 300-acre, two-cultivation scenarios are presented in Table 4.6.

Costs for owning and operating different types of cultivators will vary according to acquisition cost, speed of operation and fuel requirements. Costs for

Table 4.6. Estimated per acre ownership and operating costs for a no-till cultivator comparing one pass and two pass cultivation programs on 100 and 300 acres.

	Cost	
	100 Acres	300 Acres
	--------- $/acre ---------	
Ownership Costs		
Depreciation and interest	9.00	3.00
Operating Costs - 1st pass		
Labor	2.30	2.30
Repair and maintenance	.20	.40
Diesel fuel and oil	.90	.90
Operating Costs - 2nd pass		
Labor	1.70	1.70
Repair and maintenance	.20	.40
Diesel fuel and oil	.70	.70
Total estimated cost per acre – one pass system	**12.40**	**6.60**
Total estimated cost per acre – two pass system	**15.00**	**9.40**

the no-till cultivator used in this example is are probably on the high end; costs for other cultivator types may be slightly lower.

Returns from mechanical management practices

To economically justify mechanical weed control practices, the returns from these practices, in the form of increased yields or reduced herbicide costs, must meet or exceed the costs. In the above 100-acre, two cultivation example, if corn is $2.50 per bushel, a corn yield increase of 6 bushels per acre or greater will pay for the $15.00 per acre cost of the cultivations. Cultivation costs will also be offset if the herbicide program can be cut by $15.00 or more through the use of two cultivations. Alternatively, some combination of yield increase and herbicide cost savings will be needed to increase returns by more than $15.00 per acre to provide the incentive for cultivation.

As discussed earlier, yield increases resulting from cultivation have often been observed, but not always. Numerous experiments and demonstrations, however, have shown that properly timed cultivation and/or rotary hoeing can enable herbicide application rate reductions of from 50% to 75 % while maintaining weed control (Buhler et al., 1995; Mulder and Doll, 1993; Mulder and Doll, 1994). Supplemental cultivations to complement reduced herbicide use are probably more important.

Examples of the costs and returns generated by replacing some herbicide with cultivation in Wisconsin are provided by on-farm demonstrations conducted by the U.W. Nutrient and Pest Management Program. Thirty-eight demonstrations from 1990 to 1996 compared full herbicide rates with half rates supplemented by one or two cultivations (Table 4.7). Herbicide costs were reduced with no significant reduction in average yields, increasing gross returns by an average of $6 per acre where the half rate was used. Gross returns for the reduced herbicide rate demonstrations ranged from $26 per acre less to $80 per acre more than with the normal rate.

Still, reducing herbicide rates may not be economically attractive for all situations. Herbicide costs represent approximately 4.5% of the total crop production expense budget, but approximately 12% of the variable costs (Proost et. al., 1996). It may be difficult to justify the increased risk of weed escapes and increased labor and management requirements in an effort to offset a relatively small proportion of total costs, but easier if one looks at the potential savings in variable costs.

Challenges to mechanical weed management

No-till

Some of the biggest obstacles to controlling weeds with mechanical cultivation occur in no-till production systems. Increased residue and hard soil surfaces can make cultivating difficult if the right cultivator is not used. In addition, no-till purists believe it is undesirable to disturb the organic matter on the soil surface more than necessary and do not

Table 4.7. Effect on corn yield of using reduced preemergence broadcast herbicide rates in combination with cultivation.

	1990 (7)*	1991 (7)*	1992 (7)*	1993 (7)*	1994 (4)*	1995 (3)*	1996 (3)*
Herbicide Rate				bu/acre			
Normal	137	142	99	112	172	114	149
Reduced with cultivation	138	147	99	104	170	112	151
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS

*(the number of replicates in that year)

Adapted from R. T. Proost, P. T. Kivlin, K. B. Shelley and K. A. Talarczyk. 1996. Proc. Wis. Fert. Aglime Pest Mgmt. Conf., Madison, WI and NPM Program. 1997. 1996 Summary of on-farm demonstration results. Univ. of Wis. Ext., Madison, WI.

Table 4.8. Suitable cultivators for conservation tillage systems.

	Reduced tillage	No-till	Till-plant (Ridge-till)
Rolling cultivator	X	X*	X
S-tine cultivator	X		
C-shank cultivator	X	X*	
Conservation tillage cultivator	X	X	X

* Performs best on friable soils with low to moderate trash.

Adapted from R. Springman, D. D. Buhler, R. T. Schuler, D. Mueller and J. D. Doll. 1989. Univ. Wis. Ext. Bull. A3483.

advocate inter-row cultivation. However, when conducted properly, early growing-season cultivation can maintain surface residue cover. With single shank, sweep-type cultivators, the soil surface can be penetrated with minimal disturbance of surface residue (Springman et al., 1989).

The benefits of cultivation in no-till probably outweigh the drawbacks. Cultivation can help prevent development of resistant weeds and reduce the build-up of tough-to-control perennial weeds often associated with no-till. It is also an essential component of a weed management system that utilizes band-applied herbicides. As with conventional tillage, one to two cultivations can substitute for a significant portion of the herbicide used in no-till where pressure from difficult weeds is not great (Buhler et al., 1995). Other advantages to cultivation in no-till include enhanced water infiltration and soil aeration. As mentioned, yield response to cultivation is often greatest under reduced-tillage and no-till systems as compared to conventional tillage.

Weather

Other challenges to mechanical weed management include unanticipated rainfall, which can both delay and reduce the effectiveness of mechanical operations. If the cultivation is needed because reduced rates of preemergence herbicides were used, however, moderate rainfall will enhance their effectiveness somewhat, reducing the need for cultivation for weed management.

Technical

Between-row cultivation can injure crop plant roots if done too close at advanced stages of root development and if done too deep. Also in no-till systems, cultivators will often create ridges that can make planting drilled soybeans and combining soybeans difficult the following season.

Timing and labor

Mechanical weed control practices often need to be completed during the same time period as other operations on a farm such as first-crop hay harvest or planting of vegetable or other specialty crops. Conflicts with other farm operations often lead to a shortage in labor. Finding labor that is skilled at cultivation is often difficult.

Summary

The use of mechanical weed control can enhance herbicide performance, help avoid the development of herbicide resistance in weeds, and allow for a reduction in herbicide use. Rotary hoeing and between-row cultivation are the most common mechanical practices in corn and soybean production.

Rotary hoes are used after planting and before between-row cultivation. Planting at the proper depth can minimize stand loss from rotary hoeing. With more than one pass across the field, seeding rates should be increased to compensate for potential stand damage. Rotary hoes are not effective on fields with high residue. Research indicates that effective weed control can be gained with two cultivations and two rotary hoeings (no herbicides) provided that planting is delayed. Timing is critical for success with rotary hoeing.

Proper timing is also important for inter-row cultivation, as is proper cultivator tool adjustment. There are few significant variations in performance among different types of cultivators studied. Conservation cultivators are especially designed to work with heavy residue cover. Cultivator guidance systems keep the cultivator on track, increasing speed while reducing operator fatigue and crop damage. Results of studies investigating the non-weed control benefits of cultivation have been inconsistent. Cultivation on the contour may help decrease soil erosion.

To justify the use of mechanical forms of weed control in terms of economic benefits, the increased returns must be as much as or greater than the costs of owning and operating the necessary equipment. In some, but not all, fields, cultivation will allow the grower to cut herbicide rates without losing yields, thereby increasing returns.

Cultivation in no-till requires specialized equipment but the benefits for weed control probably outweigh the drawbacks caused by disturbing the soil surface. Unexpected rainfall and timing conflicts with other farm operations can be obstacles to successful cultivation.

Another helpful reference on mechanical weed control.

- *Steel in the Field: A Farmer's Guide to Weed Management Tools,* (Greg Bowman, ed. 1997. Sustainable Agriculture Network) provides more information on rotary hoes, cultivators, guidance systems and other mechanical weeding tools. Includes detailed pictures of a wide range of machinery. To order, call from Sustainable Agriculture Publications at (802) 656-0471.

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5

Chemical Weed Management Strategies

Herbicides have become the primary weed management tool used by many farmers after planting corn and soybean. A 1990 pesticide use survey found that 93% of corn and 94% of soybean acreage in Wisconsin was treated with a herbicide (Table 5.1). The survey also found that 69% of corn and 17% of soybean acreage was cultivated.

The judicious use of herbicides is, and will continue to be, an important part of an integrated weed management system. However, a chemical strategy should be only one part the system. In Chapter 2, we discussed how the dependence on any one method of weed management, whether mechanical, cultural or chemical, will create unforeseen problems.

This chapter explores concepts that can be used to build an effective integrated weed management strategy that includes herbicide use. This involves determination of the best application timing and selecting the best herbicide(s) based on weed populations, tillage practices, soil and herbicide properties, past experience, and cost effectiveness along with environmental protection.

Selecting the right herbicide application timing(s)

Decisions regarding herbicide applications must be made using all of the information available from the farmer, extension service, crop consultant, agronomist and product label. This information will guide the choice of the best herbicide application for a given situation. The following information presents both the pros and cons of the most commonly used herbicide application methods. The correct application for a situation depends on several factors including type of herbicide, weed species, tillage operations, and crop.

Fall applications

Fall applications of herbicides have been used for years. The rationale behind fall applications is to prevent weeds from becoming established in the spring. This is an effective and recommended strategy to manage many perennial weeds such as quackgrass and dandelions. For example, an application of non-selective systemic herbicides in the fall

Table 5.1. Herbicide and cultivator use in Wisconsin by crop, 1990.

	---- Herbicide use ----		---- Cultivator use ----	
Crop	No. of acres	% of total crop acreage	No. of acres	% of total crop acreage
	(x 1000)		*(x 1000)*	
Corn	3,426	93	2,542	69
Soybean	411	94	77	17
Oats	104	12	--	--
Wheat	48	23	--	--
Barley	6	9	--	--
Hay	38	1	--	--

Source: Wisconsin Agricultural Statistics Service. 1991. Wisconsin 1991 Pesticide Use. Wis. Dept. Ag. Trade and Consumer Protection, Madison.

before no-till planting corn into an old alfalfa stand in the spring can control both quackgrass and alfalfa.

Systemic herbicides work better in the fall than in the spring for perennial weed control because in the fall plants are sending sugars down to their roots or rhizomes for winter survival. As the herbicide moves primarily with the sugars to actively growing portions of the plant, this results in better translocation of the herbicide into the weed. In addition, winter stresses help to kill the herbicide-injured weeds. In the spring, the reverse process is occurring; sugars, nutrients and water are moving up through the plant. This upward flow results in less movement of herbicides to the roots in the spring.

In contrast to systemic herbicides, fall applications of soil-applied, residual herbicides are not recommended because of inconsistency in effectiveness, higher costs, and the potential for environmental impacts. This is unfortunate because farmers may have more time in the fall than in the spring to apply herbicides.

Research has shown that fall applications of soil-applied herbicides may not adequately control summer annual weeds the following spring. Since it does not work consistently, applying herbicides in the fall for annual weed control does not make sense economically. In addition, the label rates of fall-applied herbicides are higher than spring rates to compensate for the loss of the herbicide through the fall, winter and early spring months (Boerboom, 1994). The higher label rate increases production costs and does not guarantee satisfactory weed control. Harvey (1996) reports that giant foxtail control ranged from 48% to 75% for fall metolachlor treatments, but 94 to 98% control was achieved with spring treatments. He found that 1.5 pounds per acre of metolachlor applied early preplant was superior to 3.0 pounds per acre applied in the fall.

The risk of environmental contamination may be increased when residual herbicides are applied to the soil in the fall. The higher herbicide rates needed with fall applications appear to increase the potential for loss to the environment. For example, when atrazine was found in Wisconsin's groundwater, one of the first changes made to the product label was to remove fall applications and set strict guidelines for time of application. While there has not been adequate research on this question, fall applications of soil-applied herbicides could have impacts on both surface and groundwater resources. A cautious approach is warranted for fall applications of soil-applied, residual herbicides.

Early preplant (EPP) applications

Early preplant (EPP) is a method of herbicide application largely developed for conservation tillage systems in the central and southern corn belt. An EPP is an application of a preemergence herbicide made 14 to 30 days before a crop is planted. Early preplant applications can effectively prevent annual weed establishment and reduce the need for spring non-selective herbicide burndown applications in conservation tillage systems. (Although, as was previously stated, fall is the preferred time for using systemic applications, it may be necessary to respray in the spring if perennial weeds are still present.)

There are three basic advantages to EPP herbicide applications.

- Since EPP applications are applied early in the spring there is a greater chance for the incorporation of the herbicide by rainfall. For soil-applied preemergence herbicides to get taken into the roots and shoots of weeds, about ½ inch of rain is required.
- Secondly, if rainfall is inadequate and consequently the treatment fails, there is time for a back-up treatment prior to or at planting.
- Thirdly, growers may have more time early in the spring to apply a herbicide.

While EPP applications have some advantages, such an early herbicide application can result in diminished late season weed control. This is less of a problem when the herbicide application is made within 10 days of planting or as a split application, or if the herbicide has long residual activity. In a split application, a portion of the herbicide is applied before planting, with the remainder applied after planting. The success of this strategy depends upon the environmental conditions and the herbicide used. Reading and following the product labels' recommended rates and timing for EPP applications is always the best approach.

A second potential problem occurs when the planter moves herbicide-treated soil away from the row. Weeds will grow in the exposed untreated strip of soil. In-row weeds are more competitive against the crop than weeds between the row and are much more difficult to control with mechanical cultivation. Postemergence applications can be made to control escaped weeds, but this increases production costs, labor requirements, and the potential for crop injury.

EPP applications can make crop changes more difficult. If cropping plans need to change for one reason or another after the herbicide has been applied, alternative crops are limited to those on the herbicide label.

Weather conditions can cause problems in timing EPP applications. A late or wet spring can force a grower to change from an EPP application to either a preemergence or postemergence application. This may require a grower to change the chosen herbicide.

The environmental impact of EPP applications may also be a concern. Since the herbicide application is made early in the spring, the potential for off-site movement increases due to the likelihood of heavy spring rains. The amount of movement that can occur is a factor of the physical properties of the herbicide, intensity of the rainfall event, erosion potential of the soil, amount of crop residue, and other characteristics of the situation. While it is difficult to predict the environmental impacts of an EPP herbicide application, it is important to consider local conditions prior to application. An EPP application should never be made to a frozen soil nor before a major rainstorm.

Preplant incorporation (PPI) applications

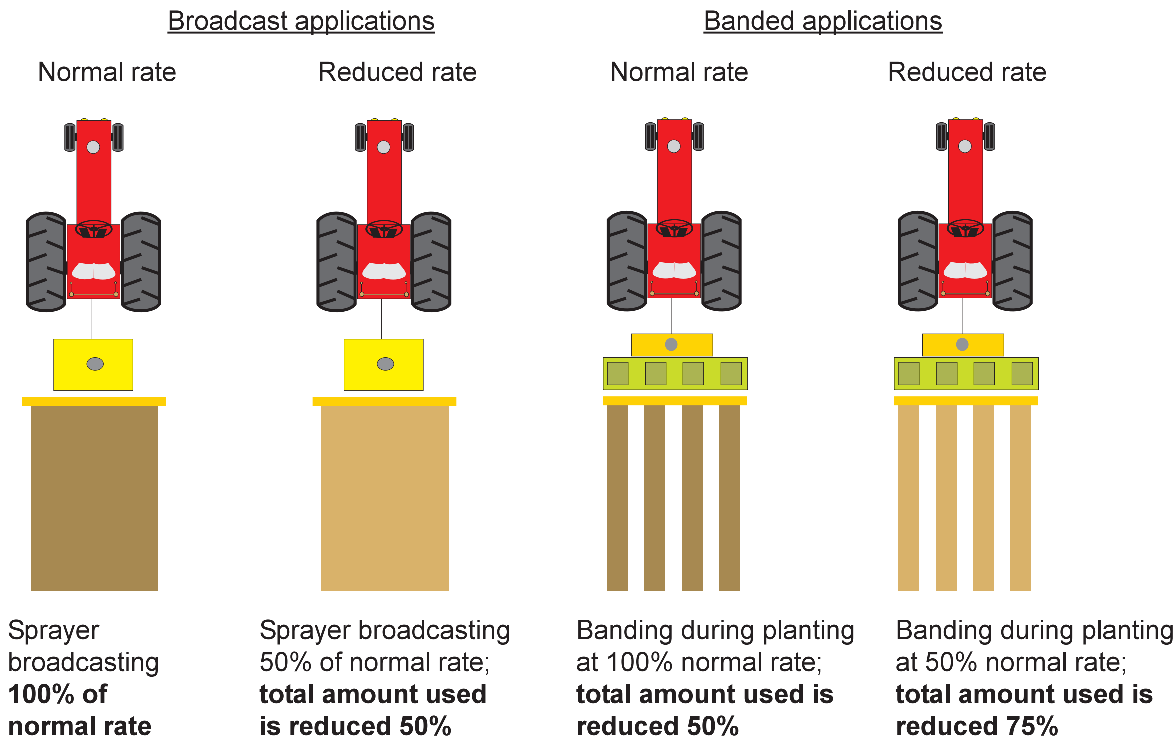
Preplant incorporation (PPI) is required for herbicides that are volatile or photodegradable such as those products found in the thiocarbamate and dinitroaniline families (e.g., EPTC is a thiocarbamate and trifluralin is a dinitroaniline). Incorporation of volatile herbicides reduces their loss to the atmosphere and may allow the herbicide to move by volatilization throughout the soil. Non-volatile herbicides, such as metolachlor and alachlor, can also be applied PPI.

Although some may also choose to incorporate other types of herbicides, secondary tillage is mandatory following broadcast applications of volatile or photodegradable herbicides to mix them into the top 2 to 3 inches of the soil. Some product labels recommend two secondary tillage passes performed at 90 degrees to each other for uniform herbicide distribution. However, growers more commonly use a single pass that includes both the spraying and the incorporation.

The major advantage of PPI is long-term consistency in weed control. Regardless of rainfall, the herbicide will be in the soil and available to control weeds.

The main disadvantage of this method is that weed "streaks" (areas where low herbicide concentration allows weeds to emerge) can appear if the incorporation is not thorough and timely. Some herbicides (e.g., alachlor) provide less weed control when applied PPI than when used as an unincorporated preemergence treatment (with adequate rainfall) because the soil dilutes the PPI treatment. Time and labor requirements are also of concern, especially if the herbicide must be incorporated twice. Furthermore, this method can not be used with con-

Figure 5.1. Methods of reducing preemergence herbicide rates.



servation tillage, because the tillage required for incorporation will not leave sufficient crop residue to meet conservation guidelines.

Preemergence (PRE) applications

Preemergence (PRE) application is the most common herbicide application method for corn. With PRE applications, the herbicide is sprayed on the field as soon as possible after the crop has been planted and prior to crop and weed emergence.

There are advantages to PRE applications. Unlike EPP applications, the herbicide is applied after planting so there is an undisrupted layer of herbicide-treated soil on the field. Also, a PRE application can be applied in a band over the row, with the area between the rows receiving no herbicide. Weeds in the between-row area can then be controlled by cultivation. This practice, known as banding, can reduce herbicide rates by 50 to 75% (Figure 5.1).

There are also some disadvantages with PRE applications. As with EPP applications, rainfall within 7 to 10 days is required to activate the herbicide by "washing" it into the soil. Usually ½ inch of rain is sufficient. If adequate rainfall is not received, most herbicide labels recommend rotary hoeing 7 to 10 days after seedbed preparation. The hoeing operation does not incorporate the herbicide; rather it kills the first flush of weeds that were not killed by the herbicide. In a no-till cropping system, a burndown application before, and in addition to, the PRE is often necessary due to the presence of existing vegetation.

PRE applications may be delayed for up to 7 days after planting, but its best to plant as soon as possible after seedbed preparation and spray as soon as possible after planting. Longer delays will increase the potential for weeds to emerge before the herbicide has been activated. Depending on weed species and herbicide, these escaping weeds may require an additional control effort because many PRE herbicides are active only on germinating weeds.

A PRE herbicide should have sufficient residual properties to provide weed control until the development of the crop canopy. The manufacturer's recommendation on the product label should always be consulted regarding specific product timing guidelines.

Postemergence (POST) applications

Many of today's newer herbicide groups (e.g.,sulfonylureas, imidazolinones) have active ingredients that require postemergence (POST) application. POST applications are made when both the crop and target weeds have emerged from the soil. Applications can be made with either a broadcast or a directed application (Figure 5.2). Several POST herbicides have residual soil activity allowing them to control both emerged weeds and subsequent weed flushes — imazethapyr and dicamba are two examples. Other POST herbicides, such as nicosulfuron and bromoxynil, lack residual activity and only kill weeds that are sprayed.

POST applications can save a grower time during the busy planting period by eliminating a PRE herbicide application. However, in situations where hard-to-control weeds such as woolly cupgrass or wild proso millet are present, applications of both PRE and POST herbicides may be required.

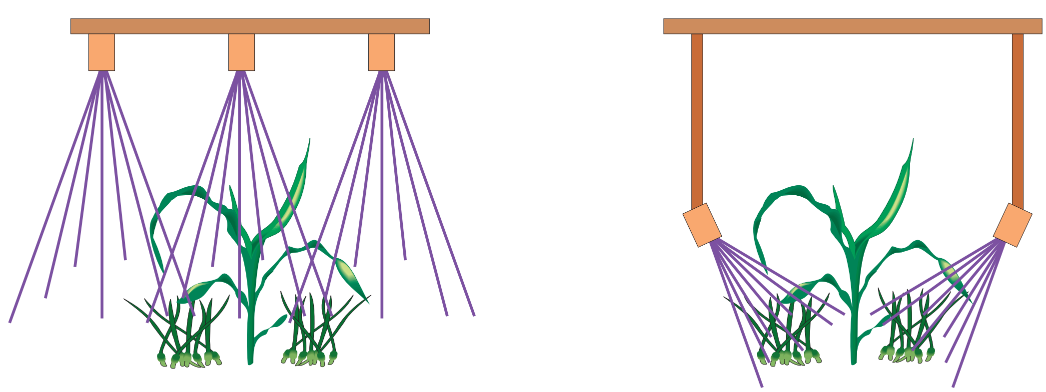
POST applications are not preventative — they are applied only when needed. They allow a grower to determine the weed species and pressure that actually exists in the field in the crop year, instead of basing herbicide selection and rate solely on last year's weed escapes. POST applications offer an additional incentive; they may actually reduce the herbicide load applied on a field. By waiting until after weed emergence, it may be determined that only spot applications of herbicide or mechanical measures are needed and the entire field does not have to be sprayed.

For a number of reasons, POST applications have been said to be more environmentally friendly than other methods of herbicide application. The herbicide spray is targeted at the weed rather that the soil. Also, the herbicide is applied at a time when the likelihood of a major rainfall event is less, and thus the potential for off-site movement should be reduced. Nonetheless, POST herbicides have been detected in surface water. A United States Geological Survey study found two POST herbicides (bentazon and triclopyr) in the Great Lakes Basin (Sullivan et al., 1996). It was not reported if the herbicide contamination originated from normal field use or from a spill.

Timing POST applications is one of the major difficulties encountered with this application method. Since many of the POST herbicides have limited residual soil activity, the application must be timed to control as many of the weeds as possible. If the application is too early, only a portion of the weed population will be controlled, requiring either another herbicide application or row cultivation to control escaped weeds. This may tempt a grower to wait longer then usual before applying the herbicide. However, if the application is made too late, the competition from weeds will have already taken a toll on crop yield (Hall et al., 1992).

Another concern with POST applications is that the potential for crop injury may increase. POST applications increase crop exposure to the herbicide. Under stressful conditions such as adverse weather or over-application of herbicides, severe crop injury can occur with a herbicide that normally causes little, if any, crop damage. Cool and humid conditions often increase the injury potential to the crop,

Figure 5.2. Broadcast versus directed postemergence applications.



Both the weed and crop get total spray coverage with a broadcast application.

The directed application covers most of the weed but only the lower portion of the crop.

but these conditions also increase the effectiveness of the herbicide on targeted weed species.

All POST herbicide labels state that the product needs to be applied to actively growing weeds. When applied to weeds under environmental stress, weed control will be reduced. In hot, dry weather, weeds often go dormant. Herbicides applied to dormant weeds are not readily absorbed, and the result can be unsatisfactory weed control. Depending on crop height, mechanical weed management measures may be more effective than a POST herbicide when weather conditions are hot and dry.

Drift, the unintended movement of herbicide spray or vapor to a non-target site, can be a problem with POST herbicide applications. Improper applications of dicamba to corn have often resulted in injury to nearby soybean fields. Care must be taken to reduce the potential for drift. Control measures include: avoiding herbicide applications when wind speed is more than 5 miles per hour; using higher spray volumes, lower nozzle pressure, and/or different nozzles to get bigger drops of spray; avoiding the application of volatile herbicides when air temperature is higher than 70 degrees; and using a chemical drift control agent in the herbicide spray.

Selecting the appropriate herbicide

Choosing the right herbicide requires being mindful of crop rotations, weed populations, tillage practices, soil and herbicide properties, available application methods, and crop variety, as well as past experience and cost-effectiveness. Proper selection and use of herbicides can reduce risks to water quality. This section will provide an overview of these factors, but will not give specific recommendations for specific weeds.

Knowing weed species and pressure

The first logical step in herbicide selection is determining the target weeds. To do this, an important question must be answered. Are the weeds seen last year the problem weed species? A weed control program needs to address the weed species and pressure that are actually in the field this year — not just the weeds that escaped last year's program. The PREDICT model, briefly discussed in Chapter 2 and detailed in Appendix A, can help do this.

The PREDICT model method requires leaving small check areas where no herbicides have been applied in fields. Another method for determining weed species and pressure is available if a PRE herbicide is applied in a band. The untreated area between the treated rows offers thousands of check strips. Prior to row cultivation, the area between the row can give the same information as the PREDICT check areas.

As discussed in Chapter 2, one of the most important pieces of information crop scouting gives a grower is a weed map. Weed maps can range from simple hand drawings made while walking fields prior to or during crop harvest, to elaborate color maps drawn by computers using global positioning satellites.

Weed maps help determine whether a weed infestation is increasing or decreasing in a given field over a number of years. They also pinpoint where spot herbicide applications will be needed. For instance, if a mapped field is free of yellow nutsedge except for one area with a heavy infestation, only that area needs a postemergence herbicide application. There is no need to spray the entire field for yellow nutsedge because it is confined to one area that has been delineated on a weed map.

Tillage

Selecting the proper herbicide and application method is an important part of managing a change to conservation tillage. Certain herbicide choices are excluded by the lack of tillage. For example, the use of volatile herbicides that require incorporation is limited in conservation tillage systems.

As explained in Chapter 3, conservation tillage systems, most notably no-till, have a dramatic effect on weed populations and dynamics. When weed population shifts occur, growers must be ready to adjust their herbicide selection process. One option is to move from PRE to POST applications. Crop residue can disrupt the uniformity of the PRE application that reaches the soil. POST applications are applied directly to the plant and are therefore not affected by residue. In addition, applying a POST herbicide three to four days later than normal may increase weed control because weeds in a no-till system tend to germinate over an extended period of time.

Soil organic matter and texture

In general, most soil-applied herbicides are less effective in soils with high organic matter contents. They are almost completely ineffective on muck and peat soils because the herbicides are tied-up by the highly reactive soil organic matter. For example, the metolachlor label lists higher application rates for soils that are between 6 and 20% organic matter than for soils with less than 6% organic matter. Metolachlor is not labeled for use on muck and peat soils (greater than 20% organic matter content).

Soil texture can also affect both herbicide selection and rate. On sandy soils, herbicides have a greater potential to leach through the soil profile and also to cause crop injury than on medium-to-fine textured soils. To compensate for this, herbicide rates are usually lower for sandy, coarse textured soils.

Realizing how soil texture and organic matter affect the performance of a herbicide can allow the grower to make an appropriate herbicide selection and rate decision. As always, the herbicide label should be read and followed.

Herbicide properties

Herbicide properties should play an important role in herbicide selection. Crop safety, weed species, effectiveness, resistance management (see next section), price, past experience with the product and crop rotation restrictions are factors commonly used to select or avoid herbicides. Potential environmental impacts and the risks from human exposure also need to be considered. These factors are clarified on the label. One other consideration that should be taken into account when selecting a herbicide, the potential for off-site movement to either surface water or groundwater, is not normally found on the herbicide label.

Combinations of many factors, some of which are poorly understood, influence off-site movement. Growers have no control over some, such as rainfall and soil texture. However, growers do have control over others, including the herbicide used and where and when it is applied. Appendix B provides a listing of herbicide properties that can be used to determine their potential for moving off-site. By reviewing these herbicide properties, growers can help avoid harmful environmental impacts. For example, if two herbicide products work equally well on the target weed species and are similar in price, but have different potentials to move off-site, the herbicide with the lower movement potential should be selected. It should be noted that the only sure way to eliminate any off-site impact is to avoid the use of herbicides altogether. However, this is not a practical option for many farmers.

Avoiding herbicide resistance

One of the most troubling concerns in weed management today is the increased occurrence of herbicide-resistant weeds. Herbicide-resistant weeds were first reported as early as the 1950’s in the world and nearly 25 years ago in the United States (Holt and LeBaron, 1990; Stoltenberg, 1995). Today more than 100 species of weeds have developed resistance to one herbicide or another, including six weed species in Wisconsin (Table 5.2). Many of the new herbicide chemistries are prone to the development of resistant weeds.

How can the buildup of resistant weed populations be avoided? The key to minimizing herbicide-resistance problems is to avoid the continual use of a herbicide with the same mode of action directed at the same target weed and to integrate mechanical operations into weed management programs.

More than 100 species of weeds have developed resistance to one herbicide or another. Common lambsquarters (above) is one of these species found in Wisconsin.

Table 5.2. Herbicide-resistant weeds reported in the north-central United States.

Herbicide family or mode of action	Weed species	State
ACCase inhibitors	large crabgrass	WI
	giant foxtail	WI
	wild oat	MN, ND
ALS/AHAS inhibitors	Palmer amaranth	KS
	common cocklebur	MO
	kochia	CO, KS, ND, NE, OK, SD, WI, WY
	Russian thistle	CO, KS, ND, WY
	shattercane	NE
	common waterhemp	IA, IL, KS, MN, MO
	smooth pigweed	KY
Dinitroanilines	green foxtail	ND
Triazines	downy brome	KS
	common groundsel	MI
	horseweed	MI
	jimsonweed	IN
	kochia	CO, IA, IL, KS, NE, WI, WY
	common lambsquarters	IN, IA, IL, MI, MN, OH, WI
	redroot pigweed	MI, MN, NE
	smooth pigweed	CO, IA, IL, IN, KY, MI, NE, OH, WI
	common purslane	MI
	common ragweed	MI
	velvetleaf	WI

Source: D. E. Stoltenberg. 1995. Proc. Wis. Fert., Aglime, Pest Mgmt. Conf. 34:225-234.

How herbicide resistance develops

The widely accepted theory explaining the development of herbicide resistance is based on natural selection. Natural selection is an ecological principle that states, within any population, individuals with characteristics allowing them to survive and to reproduce under the existing conditions will be the ones that produce a surviving generation. A population that is less adapted to those conditions will ultimately disappear.

Weeds, unlike crop plants, have tremendous genetic variation. The differences in genetic make-up are what give rise to herbicide-resistant weeds. Scientists believe that for any herbicide application on any field there are weeds that are resistant that particular herbicide. These resistant weeds (referred to as resistant biotypes) are present in extremely small frequencies, perhaps less than one in a million. Thus, the resistant biotypes are not a problem until a herbicide is used continually against the same species of weed. The herbicide acts as powerful pressure for natural selection favoring the resistant biotypes. The susceptible population is no longer the surviving population — instead the resistant biotype becomes the dominant population. This is why the rotation of herbicides helps avoid or delay the occurrence of resistance.

To illustrate, an atrazine-resistant broadleaf biotype is probably present in most fields. Continual use of atrazine year-after-year controls the larger susceptible population, and allows the resistant biotype to increase. The resistant biotype then becomes the dominant population. Biotypes that are resistant to herbicides that have particular modes of action are unlikely to also be resistant to herbicides with a different mode of action. If a different broadleaf herbicide had been used in some years, it is more unlikely that the resistant biotype would have become dominant.

Herbicides work by interfering with specific metabolic processes in plants; the process that is disrupted is called the herbicide's *mode (or site) of action*. The majority of metabolic processes that herbicides interrupt are unique to plants. This accounts for the low mammalian toxicity of most herbicides. There are three ways that a weed can become resistant to an applied herbicide.

- An alteration at the target site of the herbicide renders the herbicide ineffective.
- Enhanced metabolism of the herbicide in the weed inactivates the herbicide before it can reach the site of action.
- The herbicide is sequestered in plant cells or tissues where it has no effect.

Weeds are more likely to develop resistance to herbicides with a very active single mode of action, such as ALS inhibitors (Table 5.3).

How to avoid the development of herbicide resistance

The best way to avoid herbicide resistance is to use a herbicide only if necessary to prevent economic loss. If a herbicide application is justified, herbicide modes of action should be rotated. No more than two consecutive applications of herbicides with the same mode of action should be made against the same weed unless other effective controls are also included in the weed management system. For a tank mix, prepackaged, or sequential

Table 5.3. Herbicide modes of action and relative resistance risk.

Mode of Action	Herbicides
High Risk	
Amino acid synthesis inhibitors. (ALS inhibitors)	Accent, Arsenal, Basis, Beacon, Broadstrike, Classic, Concert, Escort, Exceed, Express, Harmony Extra, Lightning, Oust, Peak, Permit, Pinnacle, Pursuit, Reliance, Telar
Lipid synthesis inhibitors	Assure II, Fusilade DX, Fusion, Option, Poast, Poast Plus, Select
Medium Risk	
Cell membrane disrupters	Blazer, Cobra, Flexstar/Reflex, Gramoxone Extra
Contact photosynthesis inhibitors	Basagran, Buctril
Systemic photosynthesis inhibitors	Aatrex, Bladex, Evik, Lexone/Sencor, Princep, Sinbar, Velpar
Pigment inhibitors	Command, Balance
Root growth inhibitors	Balan, Prowl/Pentagon, Sonalan, Treflan
Low Risk	
Amino acid derivatives	Roundup Ultra, Touchdown, Liberty
Growth regulators	Banvel/Clarity, Butyrac, Crossbow, MCPA, Thistrol, Stinger, Tordon, 2,4-D
Shoot growth inhibitors	Dual, Eradicane, Frontier, Harness, Partner/Micro-Tech/Lasso, Ramrod, Ro-neet, Harness/Surpass/TopNotch

Source: C.M Boerboom, J. D. Doll, R.A. Flashinski, C.R. Grau and J.L. Wedberg. 1996 Field Crops Pest Management in Wisconsin.Univ. of Wisconsin Extension Publication A3646.

treatments, products with multiple modes of action should be used. Crop rotation and mechanical weeding measures also help to avoid developing resistance. Scouting fields regularly and responding quickly to increases in weeds with suspected herbicide-resistance (see Table 5.2) will help to avoid their spread (UWEX, 1994).

Calibrating herbicide sprayers

Sprayer calibration is a simple task that generally does not get the attention it deserves. It is required for proper herbicide performance. Calibration assures the applicator that the sprayer is uniformly applying the correct rate of herbicide. Herbicides that are applied in excess can result in herbicide carryover problems, crop injury, and increased potential for groundwater and surface water contamination. Conversely, herbicides that are under-applied can result in marginal weed control and necessitate the additional cost of another weed management measure that, in turn, can reduce a grower's profit.

Many of the new herbicides on the market are more expensive than older herbicides and are applied at fractions of an ounce per acre, instead of pounds per acre. A seemingly small over-application of these herbicides can result in a larger herbicide bill. For example, assume herbicide X costs $26.00 per ounce and is applied at 2/3 of an ounce per acre. This herbicide treatment's cost is $17.42 per acre. If the sprayer is over-applying by 15% (17 gallons per acre instead of 15), the herbicide cost increases to $20.03 per acre. This increased cost is only due to additional product cost, it does not include potential yield loss due to crop damage or environmental pollution from over-application. Sprayer calibration is an essential component of a weed management system.

Sprayers should be calibrated at least once a year. (See Figure 5.3 for calibration details.) If the materials sprayed are corrosive (e.g., 28% UAN) or abrasive, the sprayer should be calibrated more often. Also, depending on nozzle type, sprayers should be calibrated more often if large volumes are applied each year. Some nozzle materials corrode more quickly than others. For example, brass wears out faster than stainless steel.

Reducing herbicide application rates with the use of supplemental cultivation

Decreasing farm profits and heightened concern about the potential impacts of herbicides on human health and the environment have increased farmer interest in reducing herbicide application rates. The use of reduced herbicide rates along with supplemental cultivation is truly an integrated weed management practice. However, many growers, commercial applicators, crop consultants, and others feel that if they use less than the normal labeled rate, they risk reductions in yield and profit. Research from the North Central states has shown that reduced herbicide rates can be effective for weed management on many fields as long as there is also at least one timely cultivation (Doll et al., 1992). As with any weed management technique there are several factors that one should consider before trying to implement such a practice. These considerations are the focus of this section.

Reducing PRE herbicide rates

Rates of PRE herbicides are determined so that they consistently provide high levels of control of many weed species under a wide range of environmental conditions. In most cases, the herbicide screening and development process does not include any mechanical weed control; only the effectiveness of the herbicide alone is tested. As a result, the labeled rates usually are higher than the rate that is effective if mechanical weed control is included in the treatment program.

In theory, spraying a herbicide at the recommended rate gives a 98% probability of successful weed control. It might seem reasonable to think that applying half the labeled rate will provide only half of the normal weed control. What really happens is slightly more complicated. The lower rate will provide effective weed control 75% to 90% of the time, but the control will not last as long (Doll et al., 1992).

Figure 5.4 shows a generalized graph of the breakdown of a soil-applied herbicide. Notice that both the normal and half-rate applications provide enough herbicide for adequate levels of weed control for three to four weeks. The normal rate provides an additional four-to-five-week period of control, after which the crop should be big enough to compete with weeds. Using the reduced rate, the herbicide no longer provides satisfactory weed control after about 4 weeks. A timely cultivation is needed to control the weeds until the crop can compete. With this timely row cultivation, the probability of successful weed control using the reduced rate is again at 98%.

Figure 5.3. An easy method of sprayer calibration

Sprayer calibration is not a difficult, time consuming task. The following method for calibrating a broadcast field sprayer is presented to show how easy calibration can be (Doersch et al., 1993). Before getting started there are a few inexpensive materials that are needed: a measuring tape, stopwatch (or a watch with a second hand), a measuring container graduated in ounces, and chemical-resistant gloves.

Step 1.

The first step in calibration is to determine if the spray nozzles are worn. To do this, fill the sprayer half full with water, collect and record the flow volume from each nozzle for one minute, then determine the average output. Any nozzle that is 5% above or below the average should be cleaned or replaced. After cleaning or replacement, check the flow rates again and determine the new average.

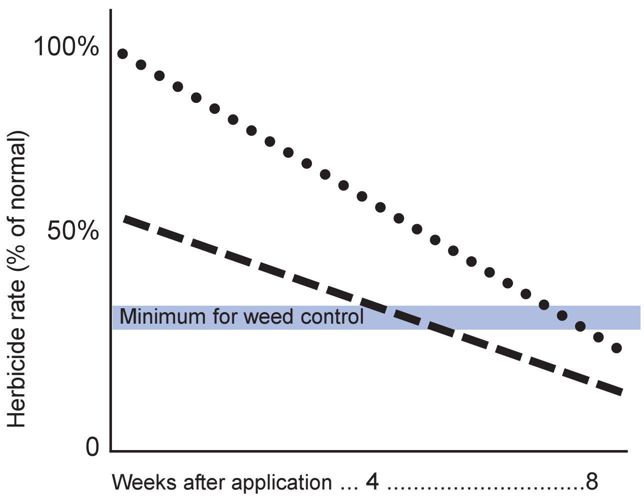
Step 2.

The second step is the actual calibration process. Again fill the sprayer half full with water. Measure the nozzle spacing in inches, and then use the table below to measure the appropriate distance in the field and mark the ends with a flag. Drive the sprayer from one end to the other of the measured distance at the speed intended to use when spraying. Record the travel time in seconds. Keeping the sprayer stationary, adjust the throttle speed to the same setting used when determining travel time. Adjust the pressure to the desired setting. Collect and record the output from several spray nozzles for the travel time and calculate the average. Collecting spray from every nozzle is not necessary because nozzle uniformity has already been determined in step one. Divide the average output, in ounces, by 2. The result is the sprayer's calibration in gallons per acre (GPA).

Broadcast nozzle spacing or band width in inches	Travel distance in feet
7	1116
10	816
14	582
20	408
30	272
40	204
60	136

If the GPA is not in the recommended range as written on the herbicide label, change the spray rate by one of three methods. For minor adjustments, adjust the pressure. Increasing or decreasing travel speed should be used for major adjustments. If necessary adjustments cannot be made with either pressure or speed, then nozzle replacement is necessary. After any adjustment, the sprayer must be recalibrated using the procedure described above.

Figure 5.4. Generalized graph of the break-down of a soil-applied herbicide.



Using the reduced rate, a timely cultivation is needed after about 4 weeks to control the weeds until the crop can compete.

■ *Broadcast applications*

University research from the across the nation has shown little difference in weed control and crop yield between a normal rate and a reduced rate with a supplemental cultivation (Doll et al., 1992). The University of Wisconsin's Nutrient and Pest Management Program has used large, field scale demonstrations to further test reduced PRE herbicide rates. As was described in Chapter 4, these demonstrations are side-by-side trials comparing a normal herbicide rate with a reduced herbicide rate with a supplemental row cultivation. Results from seven years of demonstrations, a total of 38 sites, showed that the reduced rate was more profitable than the normal rate about 90% of the time (Proost et al., 1996; NPM Program, 1997).

■ *Banded applications*

Despite favorable research and demonstration data, the notion of reducing rates of PRE broadcast herbicides causes many farmers and crop advisors to worry about weed control failures. Band applications of PRE herbicides are an alternative to broadcast applications.

In banding, the normal herbicide rate is applied in a zone over the row during planting, using even, flat spray nozzles. Even spray tips apply uniform coverage across the spray pattern whereas standard spray tips provide less coverage at the ends of the spray pattern, as shown in Figure 5.5. (The uneven coverage with standard spray tips is why spray patterns must overlap by 30%.) Row width and band width determine the per acre herbicide rate, e.g., a 15 inch herbicide band over a 30 inch crop row equals a 50% reduction of herbicide on a per acre basis. This band will provide the expected degree of weed control within the row, but provides no weed control between the row.

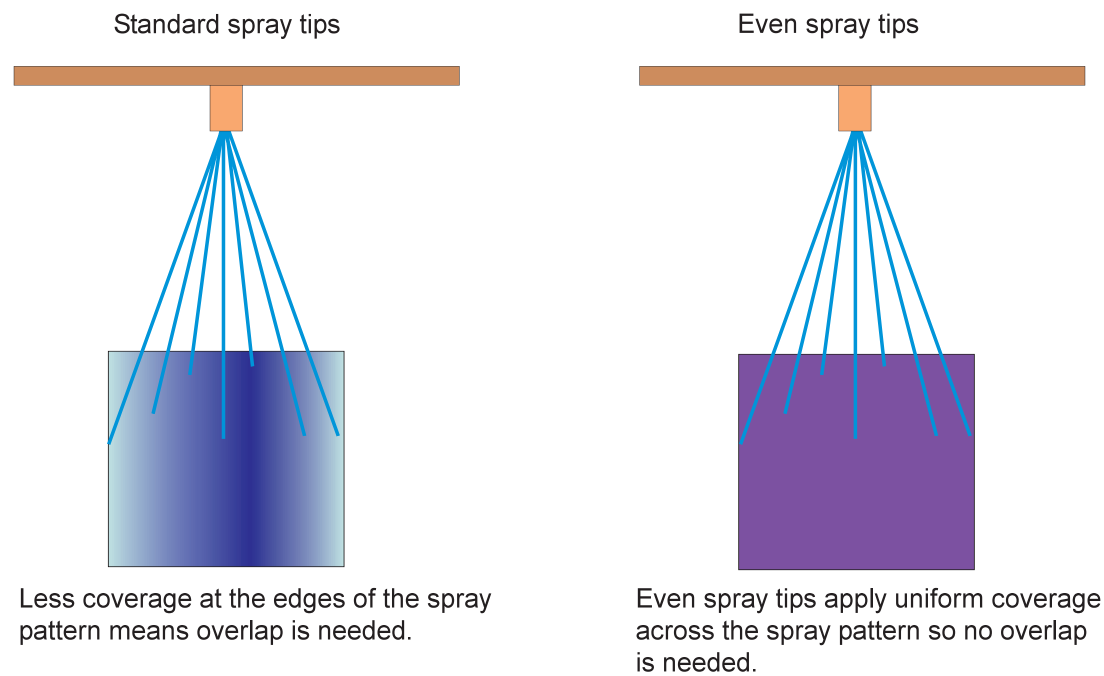
Similar to reduced rates of broadcast-applied herbicides, banding a herbicide locks you into at least one timely row cultivation to control weeds between the row. Row cultivation is even more important with banding since there is no herbicide between rows. If weather conditions do not allow timely row cultivation, weeds between the row will compete with the crop. Refilling the sprayer tank while banding can also slow crop planting. It may be for these reasons that less than 10% of Wisconsin farmers band-apply herbicides.

Reducing POST herbicide rates

Reduced POST herbicide rates have been used successfully in many research trials. A current study in six North Central states, with a total of 32 sites, has shown promise in reducing POST herbicide rates in drilled, no-till soybeans (Harvey, 1995). Harvey reports that, "Averaged over all 32 trials, the single application of the 50% rate or two applications of the 25% rate resulted in the greatest net return, \$248/acre, while the full rate and the 25% rates had the lowest net return, \$233/acre and \$229/acre, respectively." The reduced rate applications in this study were made when weeds were very small, 6 days after emergence for the 25% rate and 12 days after emergence for the 50% rate.

Other studies have also suggested that weed size is important to the success of reducing POST herbicide application rates. The University of Missouri has general guidelines for POST herbicide applications for annual broadleaf control in soybean (DeFelice and Kendig, 1994). If weed seedlings are ¼ to ½ inch tall, rates can be decreased by 75%. Rates can be reduced up to 50% for weeds between ½ and 1 inch tall. Weeds 1 inch and taller require the normal label herbicide rate. It is very important to remember that these are general guidelines that were developed in Missouri and may not be appropriate for Wisconsin.

Figure 5.5. Coverage differences across the spray area by two types of spray tips.



Farmers should be cautious when trying reduced POST herbicide rates in soybeans until more research data is available. Harvey (1995) suggests that growers start cautiously at first by trying this approach on "… small acreage and reducing rates by only 25% rather than 50%." Further rate reduction decisions can then be based on experience.

Research is underway investigating reducing POST rates in corn. To date, however, there is not enough information to determine if it will be feasible.

Important considerations before reducing rates

A reduced herbicide rate program is not a strategy for every farm or every field. An important consideration is the weed species and pressure in each field. A field with a weed problem that is not controlled with a normal rate is not a suitable candidate for a reduced herbicide rate program. This is especially true for fields with hard-to-control weeds such as wild proso millet, woolly cupgrass, shattercane and perennials. Crop rotation to alfalfa is a better option.

Management is the key to making reduced rates work. However, management requires time. Reducing rates may look good during winter planning, but when a farmer has to make first crop alfalfa and cultivate the reduced rate field at the same time, it may not look as good. A farmer must answer the question "Do I have the time necessary to make this system work?" If the answer is yes, there are still a few other factors that need consideration.

One item to consider is the current herbicide rate. If the rate is near the upper limit of the labeled rate, then it can probably be reduced with little risk of failure. However, if the application rate is near the lowest labeled rate, there may be more risk, depending on weed species and pressure. Starting with a 25% rate reduction and then proceeding cautiously is advisable.

Another item for consideration is liability. Once application rates have gone below the lowest labeled rate, the manufacturer is no longer liable for herbicide non-performance. The farmer assumes responsibility. For this reason, many commercial applicators refuse to apply herbicides below the labeled rate.

Herbicide resistant crops (HRCs)

Herbicide resistant crop (HRC) technology is advancing rapidly. HRCs are crop hybrids or varieties that are resistant to herbicides that would normally kill that crop. The herbicide resistant varieties that are being developed now are of the major agronomic crops for which there are many herbicide products. Examples include STS soybean, SR corn, Roundup Ready soybean, Liberty Link corn and soybean, and imidazolinone-tolerant and resistant (Pursuit, Resolve, Lightning, and Pursuit Plus) corn hybrids.

Attention has been focused on many HRCs because they were developed with biotechnology. Also leading to scrutiny, HRCs are the only purchased input directly tied to the purchase of another input, i.e., the purchase of Roundup Ready soybean is closely related to the purchase of Roundup Ultra herbicide.

Some of the potential and advantages and disadvantages of HRCs are identified below. A number of questions remain about HRCs. It is important to recognize that the development of HRCs is not a revolution in weed management, but rather the addition of a weed management tool (Duke, 1996). The extent that farmers will adopt HRCs will depend almost entirely on their cost effectiveness for certain situations.

Potential advantages

One of the potential advantages of HRCs is that they may allow a farmer to simplify weed management. For example, a farmer who ordinarily would use both PRE and POST applications might forego the PRE herbicide when growing Roundup Ready soybean. In addition, HRCs partnered with highly effective POST herbicides may allow farmers to wait until they can see the actual weed pressure in a field before making weed management decisions. Furthermore, use of HRCs may reduce environmental risk because the associated herbicides are often more environmentally benign than other herbicides. Other potential advantages are management of herbicide resistant weeds (e.g., atrazine-resistant weeds can be controlled with Roundup in a Roundup Ready soybean field) and reduced herbicide carryover (most HRCs use POST applications and not applied directly to the soil).

Potential disadvantages

One potential disadvantage to HRCs is that the gene allowing resistance may outcross to weedy species, creating a herbicide resistant weed. Some believe that this is a serious concern and will complicate future weed management. Others believe this will not be a problem. They think that it is unlikely that the gene will be able to outcross to common weed species because the weeds are not "wild" ancestors of the crops.

A second potential disadvantage is that the HRC itself may become a problem weed in another crop. For example, volunteer plants from a Liberty Link corn hybrid growing in Liberty Link soybeans will not be controlled by the application of glufosinate (Liberty). It can be controlled by a POST application of a grass herbicide, but that represents an additional cost that might not have been necessary if the corn was not resistant.

Other potential disadvantages are drift from the sprayer to susceptible crops and crop injury problems due to lack of thorough sprayer cleaning (Boerboom and Doll, 1995). Drift from an application of Roundup Ultra to Roundup Ready soybean, for example, may kill non-resistant crops in adjacent fields.

Economics of weed management systems

Chemical weed management has been extremely efficient in terms of time and labor. Herbicide use has allowed farmers to devote more time to a livestock enterprise and/or to expand their grain enterprise. However, these benefits have associated production costs. The two partial budgets below compare the production costs for a first year corn crop following alfalfa and a second year corn crop with three different weed control systems. The systems are a normal-rate herbicide application system, an integrated system using both mechanical and chemical weed control methods, and a system that uses mechanical weed control only.

These partial budgets assume that there are no differences in cost other than those listed. They do not take yield into consideration, as they only look at costs, not profits. However, from university research, demonstrations, and on-farm trials conducted by farmers, it is fairly safe to assume equal yields within each comparison. This comparison also does not include opportunity costs of time spent in more profitable enterprises.

Machinery costs are from the *Minnesota Farm Machinery Costs Estimates* (Fuller et al., 1994). These costs assume farmer ownership of machinery; they are not costs associated with custom operations. Equipment costs are the sum of tractor, implement, repair, lubrication and fuel expenses.

For this example, it was assumed that the farmer would spray the herbicide treatments. Expenses will be higher for the systems that use herbicides if they were custom applied. Custom herbicide application charges can vary depending on acreage sprayed.

Labor is set at $7.50 per hour. As in the budget example in Chapter 4, a 25% addition in time and labor for rotary hoe and row cultivation operations is included to account for hook-up, inter-field travel, turning in the field, and refueling.

Herbicide costs are taken from the UW Department of Agronomy's *1997 Herbicide Price List* (Boerboom, 1997). This list is an average of prices from several sources. It does not include the costs of adjuvants and is only the approximate cost.

Weed management in first year corn after alfalfa

Integrated weed management is probably the easiest in first year corn following alfalfa because such fields often contain low annual grass weed pressure. This allows the farmer to substitute a rotary hoeing for a grass herbicide. In this comparison, shown in Table 5.4, the normal herbicide application rate is based upon recommendations from agricultural suppliers. The integrated system is based upon recommendations of university advisors. The mechanical system is based on systems currently used by organic growers. All comparisons are in a tillage-based farming system.

The first scenario uses a fall application of Roundup Ultra to control alfalfa, quackgrass and dandelions. PRE Harness and POST Marksman are used to control a broad spectrum of most annual weed species. This system depends totally on herbicides for weed control. The farmer in this scenario does not cultivate. It is a "plant, spray, and harvest" system. While this system is the most expensive — total costs are $45.87 — it demands the least time and labor from the farmer for weed control, only 9 minutes per acre. For farmers that are capital rich and labor poor, this system may be advantageous. However, for farmers with a little more time, the integrated approach may be the most advantageous.

The integrated system scenario also makes use of a fall application of Roundup Ultra for alfalfa, quackgrass and dandelion control. However, the spring herbicide load is decreased. Only ½ pint of Banvel per acre is used to control annual broadleaf

Table 5.4. Partial budgets for weed control in first year corn following alfalfa.

	Normal herbicide rate system		Integrated system		Mechanical only system	
			treatments and costs per acre			
Herbicides	Roundup (2 qt)	$17.49	Roundup (2 qt)	$17.49		
	Harness (1.8 pt)	$16.71	Banvel (1/2 pt)	$ 5.63		
	Marksman (2.0 pt)	$ 7.05				
Equipment	Spray trip (3x)	$ 3.48	Spray trip (2x)	$ 2.32		
			Rotary hoe (1x)	$ 2.27	Rotary hoe (2X)	$ 4.54
			Row cultivation (1x)	$ 4.15	Row cultivation (2x)	$ 8.30
Labor	Spray trip (3x)	$1.14	Spray trip (2x)	$ 0.76		
			Rotary hoe	$ 0.69	Rotary hoe (2X)	$ 1.38
			Row cultivation	$ 1.29	Row cultivation (2x)	$ 2.58
Total dollars		**$45.87**		**$34.60**		**$16.80**
Time	Spray trip (3x)	9 min.	Spray trip (2x)	6 min.		
	Rotary hoe (1x)	5.5 min.	Rotary hoe (2x)	11 min.		
			Row cultivation (1x)	10.3 min.	Row cultivation (2x)	20.6 min.
Total time		**9 min.**		**21.8 min.**		**31.6 min.**

weeds. Annual grasses are controlled with one timely rotary hoe operations. Banvel is applied when broadleaf weeds are 1 to 2 inches tall. The row cultivation is planned about 10 days after the Banvel application. This system lowers weed management cost to $34.60 per acre, but doubles time to 21.8 minutes per acre. This system works well for farmers who have the necessary equipment and time for the mechanical operations.

The mechanical-only system scenario has no herbicide cost, but equipment and labor cost $16.80 per acre. It makes use of two rotary hoeings and two cultivations. The two row cultivations will control annual broadleaf weeds and quackgrass. While this scenario has no herbicide costs, it is the most time-consuming system, requiring nearly 32 minutes per acre to control weeds. This system may be appropriate for those farmers that have the necessary equipment and time and also for those who are trying to farm organically.

Weed management in second year corn

Weed management in second year corn can be more difficult than in first year corn following alfalfa because annual grass pressure often increases in the second year. However, the total herbicide cost is less because the fall Roundup application is not needed.

A typical corn herbicide program is the basis for the normal rate comparison in Table 5.5. The total cost is $32.21 per acre. Rates increased slightly to compensate for higher weed pressure. This program gives good control of annual broadleaf and grassy weeds. As in the previous example, this system is totally dependent on herbicides for weed control. Thus the farmer is able to spend more time elsewhere.

The integrated system cuts the herbicide rate and cost in half. Even further reductions are possible depending on weed species and pressure. Since grassy weed pressure will probably increase in the second year, a grass herbicide is included. Total cost is $23.09 per acre; however, the time commitment increases 10 minutes per acre to 16.3 minutes per acre. At least one row cultivation is required, accounting for the increase in time. This program's time and labor demands often conflicts with other farming operations, such as the first alfalfa harvest.

Table 5.5. Partial budgets for weed control in second year corn following alfalfa.

	Normal herbicide rate system		Integrated system		Mechanical only system	
	treatments and costs per acre					
Herbicides	Harness (2.0 pt)	$18.56	Harness (1.0 pt)	$9.28		
	Marksman (3.0 pt)	$10.57	Marksman (1.5 pt)	$5.29		
Equipment	Spray trip (2x)	$ 2.32	Spray trip (2x)	$ 2.32		
					Rotary hoe (2X)	$ 4.54
			Row cultivation (1x)	$ 4.15	Row cultivation (2x)	$ 8.30
Labor	Spray trip (2x)	$ 0.76	Spray trip (2x)	$ 0.76		
					Rotary hoe (2X)	$ 1.38
			Row cultivation (1X)	$ 1.29	Row cultivation (2x)	$ 2.58
Total dollars		**$32.21**		**$23.09**		**$16.80**
Time	Spray trip (2x)	6 min.	Spray trip (2x)	6 min.		
					Rotary hoe (2x)	11 min.
			Row cultivation (1x)	10.3 min.	Row cultivation (2x)	20.6 min.
Total time		**6 min.**		**16.3 min.**		**31.6 min.**

Rarely will one find a conventional farmer depending totally on mechanical weed control in second year corn. Most farmers realize that if the crop is not rotated, the risks of weed control failure in this system are high. While the comparison shows two rotary hoeings and two row cultivations, it is possible that weed pressure may necessitate an increase in the number of these operations in order to gain acceptable control.

Mechanical-only is the least expensive but most labor-intensive program. Total weed control costs are $16.80 per acre, with a time commitment of 31.6 minutes per acre. Again, for many farmers this time demand may be too much. However, for those who wish to gain premium prices for organic produce, or that lean toward organic production, this system could serve well.

Building an integrated system

The key to integrating mechanical and cultural components with chemical weed control is to take a critical look at the farm operation and determine the time and labor requirements for each farming enterprise. The best intentions to use an integrated system are of no value if time and labor are lacking. It requires a critical look at other farming operations that may interfere with a planned weed management system - operations such as alfalfa harvest, livestock management, etc. Based upon these factors a conscientious, intelligent decision can be made on herbicide use. That decision must include determination of the best herbicide application method and selection of a herbicide based on weed populations, tillage practices, soil and herbicide properties, past experience, cost effectiveness, and environmental protection.

Summary

Chemical weed management will continue to be an important part of integrated weed management systems. To select the best herbicide application for a given system, the farmer will need to pick the appropriate herbicide application timing(s). Fall, early preplant (EPP), preplant incorporation (PPI), preemergence (PRE), and postemergence (POST) applications are appropriate in different situations. Selecting the right herbicide for weed control requires considering the weed species and pressure, tillage patterns, and field soil characteristics. The properties of the herbicides themselves should be considered in order to choose ones that will be less likely to cause off-site contamination of water resources.

The development of herbicide resistant weeds can be guarded against by avoiding repeated use of herbicides with the same mode of action in a field. Sprayer calibration is important to avoid over- or under-applications of herbicides. PRE and some POST applications can be reduced by half without loss of weed control if there is also at least one timely row cultivation. Banding is another cultivation-dependent method for reducing herbicide rates.

Herbicide resistant crops (HRCs) provide a new weed management tool with potential advantages and disadvantages.

In first year corn following alfalfa, a system that integrates both mechanical and chemical methods of weed control is less costly, but more time-consuming, than an equally effective one that uses herbicides alone. A system that relies solely on mechanical methods is even less costly, but also more time-consuming. These same patterns are observed when comparing weed control systems for second year corn. Integrating mechanical and cultural components of weed control with herbicides requires adequate time and labor. ■

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Appendix A

A Simple Technique for Predicting Future Weed Problems

R. Gordon Harvey, Department of Agronomy
University of Wisconsin-Extension Publication A3565

Many Wisconsin field corn, sweet corn and soybean fields have very low weed pressure because of years of good weed management. These fields are the best sites for reducing herbicide usage. Systems that depend on cultural and mechanical weed control strategies or reduced herbicide application rates will be most effective in fields with low weed pressure.

Unfortunately, it has been difficult to predict a field's actual weed pressure. Until now there hasn't been an easy way to see how many weeds would have been present without any weed control measures. Weeds that have escaped each season's weed control strategies are not a true measure of the weed pressure.

The technique described in this publication can help you better understand weed problems and more wisely choose weed management programs. This technique is based on the following assumptions:

- As long as escaped weeds are not allowed to seed profusely, next year's weed pressure will be similar to this year's weed pressure.
- Crop yield reductions from all weed species are similar when compared on a weed volume per area rather than number per area (population) basis.
- A given weed population will produce similar weed pressure ratings in field corn, sweet corn and soybeans.

Estimate Weed Pressure

When applying herbicides, leave untreated check areas (approximately 10 by 10 ft.) in at least three representative locations within each field. This can be easily done by spreading plastic tarps on the ground prior to herbicide application, or by simply turning off one section of spray boom for a short distance at appropriate sites in the field. Remove the plastic tarps shortly after spraying. Flag or stake the check areas so they can be easily located later. Success depends on letting as many weeds germinate as possible.

If you normally rotary hoe and/or cultivate, then rotary hoe and/or cultivate right through the check areas. Your resulting weed pressure estimate will then help you determine what weed management practices are needed beyond the rotary hoeing and/or cultivation. If you are not certain whether you will rotary hoe and/or cultivate in future years, then lift these tillage tools before crossing the check areas.

When field or sweet corn plants are 25 to 30 inches tall, or soybean plants are 12 to 15 inches tall (approximately 40 days after planting), determine weed pressure in each check area by visually estimating the percentage that weeds contribute to the total volume of both crop and weeds. The enclosed photographs may help demonstrate the procedure. Identify the major weed species and estimate their contribution to the total weed pressure. Keep annual records of observations on a form similar to the sample record sheet.

The untreated check areas can be compared with treated parts of your field to determine how well your current weed management program has worked. They will also help you determine whether herbicides caused crop injury.

After you observe the check areas, keep weeds from going to seed. You can spray a 2% solution of Roundup using a hand sprayer and use leftover mixture to control patches of perennial weeds such as Canada thistle, field bindweed and common milkweed. Don't worry about killing the crop when hand spraying. The value of corn from three 10 x 10 ft. check areas is less than $3.

Predict Crop Yield Loss

Use Table 1 (next page) to calculate your predicted percent yield loss if no weed control program for the field is implemented. This data was derived from University of Wisconsin weed control trials conducted over a 6-year period including 1,640 field corn, 138 sweet corn and 1,374 soybean treatments.

Table 1. Anticipated crop yield losses from various weed pressures with no weed control.

Weed pressure rating	Severity of weed problem	Predicted yield loss	
		Field or sweet corn	Soybeans
80%	Very severe	68%	63%
40%	Severe	34%	54%
20%	Moderate	17%	36%
10%	Low	9%	20%
5%	Slight	4%	10%

Using This Information When Planning

You can use the anticipated yield loss from your observation and table 1 to judge the economic sense of different weed control options for the next year. To do this, multiply the predicted percent yield loss by your bushels per acre yield goal to give a predicted bushels per acre yield loss. Multiply the bushels per acre yield loss by the anticipated price per bushel to get the predicted dollars per acre loss.

Compare the predicted dollars per acre loss to the costs of different weed control options. Choose your weed management strategy so as not to exceed the loss that you might incur without weed control. When calculating costs of weed management options, include costs of mechanical practices such as rotary hoeing and cultivating, costs of herbicide applications, and costs of herbicides. For example, according to Minnesota Extension economists, total cost for cultivation with a 6-30 inch row cultivator is $4.90 per acre, operating a 16 ft. rotary hoe costs $2.74 per acre, and total cost for operating a 30 ft. sprayer is $2.25 per acre.[1] When planning, consider the costs of possible weed management options based on your costs or the custom rates for your area. Also look at the contribution of different weed species to total weed pressure when deciding among options.

Note that this procedure ***does not*** imply that one need not control weeds. Rather, when weed pressures are low, less intense weed management systems that require less herbicide use should provide adequate weed control.

Three Examples from Sample Record Sheet (on next page)

Field 1. Field 1 is infested with giant foxtail, pigweed, velvetleaf and lambsquarters. Weed pressure and contribution of each weed species present were similar in each year indicating no major changes in weed problems. Average weed pressure for the past three years was 6%, 8% and 7%, respectively. Thus, anticipate weed pressure of about 7% for next year. The predicted yield loss without weed control measures (from table 1) is about 6% for field and sweet corn and 14% for soybeans. Field 1 will be corn next year. If your corn yield goal is 150 bushels per acre and the expected price of corn is $2.25 per bushel, the maximum crop value loss per acre would be 0.06 *x* 150 *x* $2.25 = $20.25. To get a return on your investment, choose a weed management strategy that is effective against the four predominant weeds but costs less than $20.25 per acre.

Field 2. Field 2 had slight weed pressure three years ago with some wild-proso millet. Wild-proso millet became the dominant weed in the past two years. Weed pressure increased annually. Control efforts must be increased to bring this weed problem under control. Anticipated weed pressure for next year is greater than 20%. Expected yield loss without treatment would be about 17% in field or sweet corn and 33% in soybeans. Wild-proso millet is the primary problem and is easily controlled in soybeans. For more information on controlling this weed, see *Wild-Proso Millet Control in Field Crops* (NCR265). Consider planting soybeans and using an appropriate postemergence grass herbicide.

Field 3. Field 3 is always cultivated when in row crops. Therefore, the three check areas were cultivated prior to estimating weed pressure the first two years. Weed pressure cannot be estimated in wheat. Assuming no serious weed problems were observed in the wheat, anticipated weed pressure for next year would be 1 or 2%. Expected yield losses with only a cultivation for weed control would be 1% in field or sweet corn and 4% in soybeans. This field is an excellent candidate for low-input weed management. Consider options like combining rotary hoeing with multiple cultivations for a completely mechanical control program, using postemergence herbicides as necessary to control weeds that escape cultivation, or using reduced rates of soil-applied herbicides in combination with timely cultivation.

[1] These figures are taken from the *Minnesota Farm Machinery Economic Cost Estimates for 1992* (AG-FO2308) available from Minnesota Extension Service, Rm. 20, Coffey Hall, 1420 Eckles Ave., St. Paul, MN, 55108-6069.

Record of percent (%) weed pressure

Field 1 records

	Year 1: Location in field	%	Year 2: Location in field	%	Year 3: Location in field	%
	50 paces from w roadway, 24 rows from fence	5	100 paces from W. roadway, 90 ft from S. fence	8	200 paces from w roadway, 36 rows from S. fence	5
	100 paces in from stake midfield in E. fence	8	200 paces in from stake midfield in E. fence	6	50 paces in from stake midfield in E. fence	9
	200 paces from w roadway, 36 rows from N. fence	5	50 paces from w roadway, 4 sprayer passes (120 ft) from N. fence	10	100 paces from w roadway, 24 rows from N. fence	7
	Crop: CORN	Ave. 6	**Crop:** Soybeans (drilled)	Ave. 8	**Crop:** CORN	Ave. 7+
	Species & percent contribution: Giant Foxtail (40%), Pigweed (25%), Velvetleaf (20%), Lambsquarters(15%)		**Species & percent contribution:** Giant Foxtail (40%), Pigweed (25%), Velvetleaf (20%), Lambsquarters(15%)		**Species & percent contribution:** Giant Foxtail (40%), Pigweed (25%), Velvetleaf (20%), Lambsquarters(15%)	

Field 2 records

	Year 1: Location in field	%	Year 2: Location in field	%	Year 3: Location in field	%
	Flagged area, NE corner	6	Flagged area, NW corner	12	Flagged area, NE corner	20
	Flagged area, west side	4	Flagged area, west side	14	Flagged area, west side	18
	Flagged area, SW corner	3	Flagged area, SE corner	11	Flagged area, SW corner	24
	Crop: Soybean	Ave. 4+	**Crop:** Sweet corn	Ave. 12+	**Crop:** CORN	Ave.20+
	Species & percent contribution: Velvetleaf (50%), Wild-proso Millet (20%), Nightshade (15%), Pigweed (15%)		**Species & percent contribution:** Wild-proso Millet (60%), Velvetleaf (30%), Pigweed (10%)		**Species & percent contribution:** Wild-proso Millet (85%), Velvetleaf (10%), Pigweed (5%)	

Field 3 records

	Year 1: Location in field	%	Year 2: Location in field	%	Year 3: Location in field	%
	200 paces from N fence, 3rd sprayer pass (90 ft) from W	3	150 paces from N fence, 48 rows from W edge	2	Not Evaluated	
	100 paces from S fence, 4th sprayer pass (120 ft) from E fence	1	150 paces from S fence, 48 rows from E edge	1	Not Evaluated	
	200 paces from S fence, 5th sprayer pass (150 ft) from W edge	2	100 paces from S fence, 60 rows from W edge	2	Not Evaluated	
	Crop: Corn	Ave. 2	**Crop:** Soybeans	Ave. 1+	**Crop:** Wheat	
	Species & percent contribution: Lambsquarters (40%), Giant foxtail (30%), Velvetleaf (30%)		**Species & percent contribution:** Lambsquarters (35%), Giant foxtail (35%), Velvetleaf (30%)		**Species & percent contribution:** Lambsquarters (not evaluated)	

Instructions: Estimate weed pressure approximately 40 days after planting in at least three check areas in each field. Contribution of each weed species is estimated as a percentage of the total weed volume.

Record of percent (%) weed pressure

	Year 1		Year 2		Year 3	
	Location in field	%	Location in field	%	Location in field	%
Field 1 records						
	Crop:		Crop:		Crop:	
	Species & percent contribution:		Species & percent contribution:		Species & percent contribution:	
Field 2 records						
	Crop:		Crop:		Crop:	
	Species & percent contribution:		Species & percent contribution:		Species & percent contribution:	
Field 3 records						
	Crop:		Crop:		Crop:	
	Species & percent contribution:		Species & percent contribution:		Species & percent contribution:	

Instructions: Estimate weed pressure approximately 40 days after planting in at least three check areas in each field. Contribution of each weed species is estimated as a percentage of the total weed volume.

Appendix B

<u>NOTE:</u> The following information was obtained from the Natural Resources Conservation Service Field Office Technical Guide for the state of Minnesota. ONLY the tables have been modified for Wisconsin.

NATURAL RESOURCES CONSERVATION SERVICE
FIELD OFFICE TECHNICAL GUIDE (FOTG) – SECTION II
WATER QUALITY AND QUANTITY INTERPRETATIONS

PART A

SELECTED PESTICIDE PROPERTIES DATABASE
AND
SOIL/PESTICIDE INTERACTION SCREENING PROCEDURE (SPISP) INSTRUCTIONS

I. Introduction

Part A, Section II, Water Quality and Quantity Interpretations of the Field Office Technical Guide (FOTG) contains a selected pesticide properties database and describes a procedure which can be used to help determine the potential for specific pesticides to move towards water resources. The <u>database</u> contains information on a number of selected pesticide properties that affect pesticide movement with water. Each pesticide in the database contains a rating for relative potential to move with runoff or leach downward. The ratings are based on the selected pesticide properties.

The <u>procedure</u> combines a pesticide's runoff or leaching rating with a soil rating developed for individual soil mapping units. The individual soil rating are found in Part B, of Section II Water Quality and Quantity of the FOTG. Combining the pesticide rating and the soil rating simulates the interaction of pesticide properties and soil properties and results in a relative rating for a soil/pesticide combination. Soil/pesticide interaction ratings are developed for both pesticide movement below the root zone and pesticide movement in runoff to a field's edge.

The soil/pesticide interaction ratings are first approximations of pesticide movement potential and should not by themselves be used to make pest management recommendations. They can however help in the decision making process.

II. Limitations

The soil/pesticide interaction ratings are considered a first approximation because of several limitations including those listed below:

A. The ratings do not consider the effects of a specific chemical on human health or non-target species from either a short term high dosage exposure or a long term low dosage exposure.

B. The ratings do not consider site specific factors that affect the half-life of chemicals (e.g. soil texture, pH, organic matter content, moisture and temperature).

C. The ratings are based on the potential for a chemical to move below the root zone or to a field's edge. Transport and other environmental fate factors beyond those zones are not considered.

D. The ratings do not consider numerous management factors that affect the fate of chemicals in the environment (e.g. application rates and application timing).

E. The ratings do not address most breakdown products or metabolites of an individual chemical.

The pesticide properties database may list chemicals not currently registered for use in Minnesota and will not be considered as a listing of approved chemicals. The Minnesota Department of Agriculture should be consulted concerning the current status of a particular chemical.

III. Soil-Pesticide Interaction Rating Procedure and Interpretation

Pesticides listed in Subpart V are rated according to potential for loss in surface runoff (combined loss adsorbed to soil particles and in solution) and loss by leaching. The database lists the pesticide properties including the leaching potential and the combined surface runoff loss potential of each pesticide. The leaching and combined surface loss potentials are rated large, medium, or small. Ratings for products which are combinations of chemicals are given for the individual chemicals. For example, CYCLE, a combination herbicide containing metolachlor and cyanazine, would receive ratings for metolachlor and cyanazine but not a rating for the combination of the two.

Pesticides in the database are also separately rated for movement in surface runoff in the solution phase or as adsorbed to soil particles. **These separate pesticide ratings cannot presently be used to develop soil/pesticide interaction ratings (see Subpart IV for uses).**

Soil mapping units are rated both on soil affects on pesticide leaching and soil combined affects on pesticide movement in runoff as carried in solution and by soil particles. The soil runoff ratings do not differentiate between pesticide movement in solution or as attached to soil particles. The slight, moderate, or severe ratings for soil leaching potential and soil combined surface loss potential are found in Part B, of section II Water Quality and Quantity, of the FOTG.

Procedure

The user should determine the water resource concern (i.e. ground water or surface water quality), then select the leaching and/or runoff procedure to evaluate potential loss of a pesticide on a particular soil map unit.

Both the pesticide rating and the soil rating are used to determine the potential for pesticide loss due to surface runoff or leaching. Follow these steps:

A. Potential Loss to Leaching

1. Find the leaching potential for the critical soil map unit from the county specific Soil Ratings for Pesticide Loss, section II Water Quantity and Quality Interpretations of the FOTG.
2. Determine the pesticide leaching potential from the pesticide database in Subpart V. If the pesticide will be applied post-emergence onto a canopy of growing crop and weeks that provides 90% or greater ground cover, reduce the potential for leaching by one class.
3. Using the matrix find the intersection of the soil leaching potential and the pesticide leaching potential. This gives the overall leaching potential rating of 1, 2, or 3. For example, a soil with a moderate soil leaching potential and a pesticide with a small leaching potential will rate as "Potential 3".

Potential Pesticide Loss to Leaching

Soil Surface Loss Potential	Pesticide Leaching Potential		
	Large	Medium	Small
Severe	Potential – 1	Potential – 1	Potential – 2
Moderate	Potential – 1	Potential – 2	Potential – 3
Slight	Potential – 2	Potential – 3	Potential – 3

B. Potential Pesticide Loss to Surface Runoff Matrix

1. Find the Soil Surface Loss potential for the critical soil map unit from the county specific Soil Ratings for Pesticide Loss, Section II Water Quality and Quantity Interpretations of the FOTG.
2. Determine the combined pesticide surface loss potential from the pesticide database in Subpart B. If the pesticide will be applied post emergence onto a canopy of growing crop and weeds that provides 90% or greater ground cover, reduce the potential for surface runoff by one class.
3. Use the matrix to determine a potential rating of 1, 2, or 3.

Potential Pesticide Loss to Surface Runoff

Soil Surface Loss Potential	Pesticide Leaching Potential		
	Large	Medium	Small
Severe	Potential – 1	Potential – 1	Potential – 2
Moderate	Potential – 1	Potential – 2	Potential – 3
Slight	Potential – 2	Potential – 3	Potential – 3

Interpretation of the Ratings

Both sets of ratings should be interpreted according to the following guidelines.

Potential 1: This pesticide applied on this soil can have a high probability of moving offsite depending on site and management conditions. The health hazards of these pesticides to humans or animals should be considered. If the potential danger to health or non-target organisms exists, alternative pesticides or alternative pest management techniques such as cultural or biological controls should be considered.

A relative idea of potential health hazards can be obtained by examining signal words on the product (e.g. Danger, Warning, Caution). Additionally Minn. Ext. Service publication **PESTICIDES: SURFACE RUNOFF, LEACHING AND EXPOSURE CONCERNS** contains information on acute toxicities of some chemicals. Limited information has been tabulated on non-human non-target species impacts.

Potential 2: This pesticide applied on this soil can have a medium probability of moving offsite depending on site and management. Additional on-site evaluation is necessary to determine the sensitivity of the water resource and the type of water resource of concern. When a potential water resource problem exists the land user should consider: 1) alternative pesticides; 2) use of band application; 3) reduced rates if possible; or 4) cultural and biological control methods.

Potential 3: This pesticide applied on this soil has a low probability of moving offsite.

IV. Pesticide movement in solution in runoff and pesticide movement in runoff as carried by soil particles.

Pesticides can move in surface runoff either in a solution phase or as attached to soil particles. The ability of an individual pesticide to move may vary between these pathways. For example, SENCOR has a small rating for potential movement in runoff as adsorbed to soil but a high rating for potential movement in runoff in solution. Ratings that approximate the ability of an individual chemical to move in surface runoff either in the solution phase or as adsorbed to soil particles are listed in Subpart V. These ratings should not be used in the pesticide/soil interaction matrix rating process until corresponding and necessary soil information has been released for matrix use. The individual chemical solution or adsorbed ratings can however be used to help select conservation practices which reduce pesticide movement. In the case of SENCOR, conservation practices that reduce runoff should be considered. Conservation practices which reduce erosion but which may not reduce runoff (e.g. tile outlet terrace) should be carefully scrutinized.

V. Pesticide Properties Database

Selected pesticide properties affecting pesticide fate and associated pesticide leaching and runoff ratings are contained in this Subpart. The data is grouped by herbicide, insecticide, fungicide, and other, and sorted by trade name within the groupings. Combination products are shown two or more times with ratings presented for each of the individual compounds in the combination. For example the herbicide BETAMIX is listed twice with selected pesticide properties and ratings given for both desmedipham and phenmedipham, the two active ingredients in BETAMIX. Appendix A contains a common name/trade name cross-reference sorted by common name.

Definitions

A. Trade name: Manufacturer's name for products. There may be many different trade names for the same pesticide. Trade names may also be associated with more than one active ingredient or with mixtures of compounds. Trade names and label use can also change rapidly. Accordingly, always check both the trade name and the common name when seeking information about a particular product.

B. Common name: The common names are generic names. They refer to active ingredient compounds without naming specific products or trade names. In some cases, one common name may be used to represent several forms of the same active ingredient. "2, 4-D", for example, is available in the acetic acid form, the ester form, and the soluble salt form. These three forms of 2, 4-D have considerable different properties, so as pesticides, they are listed separately in the database.

C. Water solubility: The solubility of the pesticides in water at room temperature is given in **mg/1** or **ppm.** This is the solubility of the pure active ingredient, not the formulated product. Solubility is a fundamental physical property of a chemical and will strongly affect the ease of washoff and leaching through soil.

pH: The pH value at which the listed solubility value is valid. A listed pH indicates that the solubility of this pesticide may change significantly at different pH values.

E: An "E" denotes the solubility rating was an estimate and may be accurate within a factor of two.

D. Soil half-life: Half-life given in days, is the time required for a pesticide in the soil to degrade by one-half. Pesticide degradation can be described by assuming that each successive elapsed half-life will decrease the pesticide concentration to one-fourth of the initial amount. Half-lives can vary by a factor of three or more from reported values depending on soil moisture, temperature, oxygen status, soil microbial population and other factors. Additionally, resistance to degradation can change as the initial concentration of a chemical decreases. It may take longer to decrease the initial concentration to one-half.

G/E: A "E" denotes the half-life rating was an estimate. Estimates were developed by comparing a compound with a known half-life to a very similar compound with an unknown half-life. A "G" denotes the half-life rating was a guess. Estimates and guesses will not be in error by orders of magnitude. They could by in error by a factor of two or more.

E. Soil Sorption Index (K_{oc}): K_{oc} or the soil organic carbon sorption coefficient measures the tendency of the pesticide to attach to soil particle surfaces. The higher the K_{oc} value the stronger the tendency to attach to and move with the soil.

pH: The pH at which the K_{oc} value is valid. A listed pH indicates that the K_{oc} of this chemical may change significantly with different pH levels.

G/E: An "E" denotes the K_{oc} rating was an estimate and could be in error by 3X-10X. A "G" denotes the K_{oc} rating was a guess and could be in error by 10X or more.

F. Pesticide leaching and runoff rating:

Leaching Potential (LP): The leaching potential indicates the tendency of a pesticide to move in solution with water and leach below the root zone. The ratings are listed as large, medium, and small with the large rating having the highest potential for leaching. The pesticide leaching potential is used in the soil/pesticide interaction screening procedure.

Combined Surface Runoff Loss Potential (CSLP): The runoff potential indicates the combined tendency of the pesticide to move with sediment and in solution in surface runoff. The ratings are listed as large, medium, or small, with the large rating showing highest combined potential to move. The combined surface runoff potential is used in the soil/pesticide interaction screening procedure.

G. Pesticide Solution or Adsorbed Surface Loss Potential:

Pesticide in Solution Surface Loss Potential (SSLP): These ratings show the relative potential for chemicals to move in surface runoff in the solution phase. The ratings should only be used to help select conservation practices which control chemical movement. **The ratings are <u>NOT</u> to be used in the soil/pesticide interaction screening procedure (soil ratings have not been developed specifically for the solution component of surface loss potential).**

Pesticide Adsorbed to Sediment Surface Loss Potential (ASLP): These ratings show the relative potential for chemicals to move in surface runoff attached to soil particles. The ratings should only be used to help select conservation practices which control chemical movement. **The values are <u>NOT</u> to be used in the soil/pesticide interaction screening procedure (soil ratings have not been developed specifically for the adsorbed component of surface loss potential).**

NRCS Selected Pesticide Properties Database and SPISP Ratings (Version 3.0)

Herbicides

Trade Name	Common Name	Water Solubility			Soil Half-life		Soil Sorption Index			Movement Potential Leaching ------ Runoff ------			
		PPM	pH	E	Days	G/E	K_{oc}	pH	G/E	LP	CLSP	SSLP	ASLP
2, 4-D Acid	2, 4-D acid	890			10		20			M	S	M	S
2, 4-D Amine	2, 4-D amine	796000			10		20			M	S	M	S
2, 4-D Ester	2, 4-D ester	100		E	10		100		E	M	M	M	S
AAtrex	Atrazine	33			60		100			L	M	L	M
AGSCO 400	2, 4-D acid	890			10		20			M	S	M	S
Accent	Nicosulfuron	22000	7		21		30			L	S	M	S
Acclaim	Fenoxaprop-ethyl	0.8			9		9490			S	L	M	M
Alanap-L	Naptalam	231000	7		14		20		E	L	S	M	S
Ally	Metsulfuron-methyl	9500	7		120		35	7		L	M	L	M
Arsenal	Imazapyr isopropylamine salt	500000		E	90		100		E	L	M	L	M
Assure	Quizalofop-ethyl	0.31			60		510	7		M	L	M	L
Atrazine	Atrazine	33			60		100			L	M	L	M
Balan	Benefin	0.1			40		9000			S	L	M	L
Banvel SFG	Dicamba	400000			14		2			L	S	M	S
Banvel/Clarity	Dicamba	400000			14		2			L	S	M	S
Barrage	2, 4-D acid	890			10		20			M	S	M	S
Basagran	Bentazon sodium salt	2300000			20		34			L	S	M	S
Basis	Rimsulfuron	*			*		*			*	*	*	*
Basis	Thifensulfuron-methyl	2400	6		12		45	7		M	M	M	S
Beacon	Primisulfuron-methyl	70	7		30		50	7	E	L	M	L	S
Bicep	Atrazine	33			60		100			L	M	L	M
Bicep	Metolachlor	530			90		200			L	M	L	M
Bladex	Cyanazine	170			14		190			M	M	M	S
Blazer	Acifluorfen sodium salt	250000			14		113		E	M	M	M	S
Broadstrike + Dual	Flumetsulam	5650	7		47		28	0		L	S	L	M
Broadstrike + Dual	Metolachlor	530			90		200			L	M	L	M
Broadstrike + Treflan	Flumetsulam	5650	7		47		28	0		L	S	L	M
Broadstrike + Treflan	Trifluralin	0.3			60		8000			S	L	M	L
Bronate	Bromoxynil octanoate	0.08			7		10000		E	S	M	S	M
Bronate	MCPA ester	5		E	25		1000		E	S	L	M	M

Movement Potential: **S** = small, **M** = medium, **L** = Large
LP = Pesticide Leaching Loss Potential
CSLP = Combined Solution and Adsorbed Surface Loss Potential
SSLP = Pesticide Solution Surface Loss Potential
ASLP = Pesticide Adsorbed to Sediment Surface Loss Potential
* = Ratings not available.

Table modified from USDA-NRCS-MN, August 1995

NRCS Selected Pesticide Properties Database and SPISP Ratings (Version 3.0)

Herbicides

Trade Name	Common Name	Water Solubility			Soil Half-life		Soil Sorption Index			Movement Potential Leaching ------ Runoff ------			
		PPM	pH	E	Days	G/E	K_{oc}	pH	G/E	LP	CLSP	SSLP	ASLP
Bronco	Alachlor	240			15		170			M	M	M	S
Bronco	Glyphosate	900000		E	47		24000		E	S	L	L	L
Buctril	Bromoxynil octanoate	0.08			7		10000		E	S	M	S	M
Buctril + Atrazine	Atrazine	33			60		100			L	M	L	M
Buctril + Atrazine	Bromoxynil octanoate	0.08			7		10000		E	S	M	S	M
Buctril Gel	Bromoxynil heptanoate	*			*		*			*	*	*	*
Buctril Gel	Bromoxynil octanoate	0.08			7		10000		E	S	M	S	M
Bugle	Fenoxaprop-ethyl	0.8			9		9490			S	L	M	M
Bullet	Alachlor	240			15		170			M	M	M	S
Bullet	Atrazine	33			60		100			L	M	L	M
Butyrac 200	2, 4-DB Dimethylamine salt	709000			10	E	20		E	M	S	M	S
Butyrac Ester	2, 4-DB Butoxyethyl ester	8			7		500			S	M	M	S
Canopy	Chlorimuron ethyl	1200	7		40		110	7		L	M	L	S
Canopy	Metribuzin	1220			40		60		E	L	M	L	S
Caparol	Prometryn	33			60		400			M	L	L	M
Cheyenne	Fenoxaprop-ethyl	0.8			9		9490			S	L	M	M
Cheyenne	MCPA ester	5		E	25		1000		E	S	L	M	M
Cheyenne	Thifensulfuron-methyl	2400	6		12		45	7		M	M	M	S
Cheyenne	Tribenuron methyl	280	6		10	E	46			M	M	M	S
Chipco Ronstar G	Oxadiazon	0.7			60		3200			S	L	M	L
Chopper	Imazapyr isopropylamine salt	500000		E	90		100		E	L	M	L	M
Clarity	Dicamba	400000			14		2			L	S	M	S
Classic	Chlorimuron ethyl	1200	7		40		110	7		L	M	L	S
Cobra	Lactofen	0.1			3		10000		E	S	M	S	M
Command 4 EC	Clomazone	1100			24		300			M	M	M	S
Commence	Clomazone	1100			24		300			M	S	M	M
Commence	Trifluralin	0.3			60		8000			S	L	M	L
Concert	Chlorimuron ethyl	1200	7		40		110	7		L	M	L	S
Concert	Thifensulfuron methyl	2400	6		12		45	7		M	M	M	S
Contour	Atrazine	33			60		100			L	M	L	M

Movement Potential: **S** = small, **M** = medium, **L** = Large
LP = Pesticide Leaching Loss Potential
CSLP = Combined Solution and Adsorbed Surface Loss Potential
SSLP = Pesticide Solution Surface Loss Potential

ASLP = Pesticide Adsorbed to Sediment Surface Loss Potential
* = Ratings not available.

Table modified from USDA-NRCS-MN, August 1995

NRCS Selected Pesticide Properties Database and SPISP Ratings (Version 3.0)

Herbicides

Trade Name	Common Name	Water Solubility			Soil Half-life		Soil Sorption Index			Movement Potential Leaching ------ Runoff ------			
		PPM	pH	E	Days	G/E	K_{oc}	pH	G/E	LP	CLSP	SSLP	ASLP
Contour	Imazethapyr	11000			90		100		E	L	M	L	M
Crop Star	Alachlor	240			15		170			M	M	M	S
Crossbow	2, 4-D ester	100		E	10		100		E	M	M	M	S
Crossbow	Triclopyr ester	23			46		780			M	L	L	M
Cycle	Cyanazine	170			14		190			M	M	M	S
Cycle	Metolachlor	530			90		200			L	M	M	M
Dacthal	Chlorthal-dimethyl	0.5			100		5000			S	L	M	L
Des-i-cate	Endothall	100000	7		7		20		E	M	S	M	S
Devrinol	Napropamide	74			70		400			M	L	L	M
Diquat	Diquat dibromide	718000			1000		1000000		E	S	L	S	L
Diquat Herbicide	Diquat dibromide	718000			1000		1000000		E	S	L	S	L
Direx	Diuron	42			90		480	7		M	L	L	M
Drexel Atrazine	Atrazine	33			60		100			L	M	L	M
Dual	Metolachlor	530			90		200			L	M	L	M
Eptam	EPTC	344			6		200			S	M	M	S
Eradicane	EPTC	344			6		200			S	M	M	S
Eradicane Extra	EPTC	344			6		200			S	M	M	S
Escort	Metsulfuron-methyl	9500	7		120		35	7		L	M	L	M
Evik	Ametryn	185			60		300			M	M	L	M
Express	Tribenuron methyl	280	6		10	E	46			M	M	M	S
Extrazine II	Atrazine	33			60		100			L	M	L	M
Extrazine II	Cyanazine	170			14		190			M	M	M	S
Formula 40	2, 4-D amine	890			10		20			M	S	M	S
Freedom	Alachlor	240			15		170			M	M	M	S
Freedom	Trifluralin	0.3			60		8000			S	L	M	L
Frontier	Dimethenamid	*			*		*			*	*	*	*
Fusilade 2000	Fluazifop-P-butyl	2			15		5700			S	L	M	M
Fusilade DX	Fluazifop-P-butyl	2			15		5700			S	L	M	M
Fusion	Fenoxaprop-ethyl	0.8			9		9490			S	L	M	M
Fusion	Fluazifop-P-butyl	2			15		5700			S	L	M	M

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NRCS Selected Pesticide Properties Database and SPISP Ratings (Version 3.0)

Herbicides

Trade Name	Common Name	Water Solubility			Soil Half-life		Soil Sorption Index			Movement Potential Leaching ------ Runoff ------			
		PPM	pH	E	Days	G/E	K_{oc}	pH	G/E	LP	CLSP	SSLP	ASLP
Galaxy	Aciflourfen sodium salt	250000			14		113			M	M	M	S
Galaxy	Bentazon sodium salt	2300000			20		34			L	S	M	S
Gallery	Isoxaben	1			100	E	1400			S	L	L	L
Garlon	Triclopyr amine salt	2100000			46		20		E	L	S	L	M
Glean	Chlorsulfuron	7000	7		160		40	7		L	M	L	M
Goal	Oxyfluorfen	0.1			35		100000		E	S	L	S	M
Gramoxone	Paraquat dichloride salt	620000			1000	E	1000000		E	S	L	S	L
Gramoxone Extra	Paraquat dichloride salt	620000			1000	E	1000000		E	S	L	S	L
Guardsman	Atrazine	33			60		100			L	M	L	M
Guardsman	Dimethenamid	*			*		*			*	*	*	*
Harmony Xtra	Thifensulfuron-methyl	2400	6		12		45	7		M	M	M	S
Harmony Xtra	Tribenuron methyl	280	6		10	E	46			M	M	M	S
Harness	Acetochlor	*			*		*			*	*	*	*
Harness Extra	Acetochlor	*			*		*			*	*	*	*
Harness Extra	Atrazine	33			60		100			L	M	L	M
Herbicide 273	Endothall	100000	7		7		20		E	M	S	M	S
Hoelon	Diclofop-methyl	0.8			37		16000			S	L	M	M
Hornet	Clopyralid amine salt	300000		E	24		300			L	S	M	S
Hornet	Flumetsulam	5650	7		47		28	0		L	S	L	M
Liberty	Glufosinate-ammonium	1370000			7		100		E	S	M	M	S
Kerb	Pronamide	15			60		200			L	M	L	M
Laddok S-12	Atrazine	33			60		100			L	M	L	M
Laddok S-12	Bentazon sodium salt	2300000			20		34			L	S	M	S
Lariat	Alachlor	240			15		170			M	M	M	S
Lariat	Atrazine	33			60		100			L	M	L	M
Lasso	Alachlor	240			15		170			M	M	M	S
Lasso II	Alachlor	240			15		170			M	M	M	S
Lexone	Metribuzin	1220			40		60		E	L	M	L	S
Linex	Linuron	75			60		400	7		M	L	L	M
Lorox	Linuron	75			60		400	7		M	L	L	M

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Lorox Plus	Chlorimuron ethyl	1200	7		40		110	7		L	M	L	S
Lorox Plus	Linuron	75			60		400	7		M	L	L	M
MCPA	MCPA dimethylamine salt	866000	7		25		20		E	L	S	M	S
MCPA	MCPA ester	5		E	25		100		E	S	L	M	M
Marksman	Atrazine	33			60		100			L	M	L	M
Marksman	Dicamba	400000			14		2			L	S	M	S
Micro-tech	Alachlor	240			15		170			M	M	M	S
Partner	Alachlor	240			15		170			M	M	M	S
Passport	Imazethapyr	11000			90		100		E	L	M	L	M
Passport	Trifluralin	0.3			60		8000			S	L	M	L
Pennant	Metolachlor	530			90		200			L	M	L	M
Permit	Halosulfuron	*			*		*			*	*	*	*
Pinnacle	Thifensulfuron-methyl	2400	6		12		45	7		M	M	M	S
Poast	Sethoxydim	4390	7		5		100		E	S	M	M	S
Poast Plus	Sethoxydim	4390	7		5		100		E	S	M	M	S
Pramitol	Prometon	720			500		150			L	L	L	M
Preview	Chlorimuron ethyl	1200	7		40		110	7		L	M	L	S
Preview	Metribuzin	1220			40		60		E	L	M	L	S
Princep	Simazine	6.2			60		130			L	M	L	M
Prowl	Pendimethalin	0.275			90		5000			S	L	M	L
Pursuit	Imazethapyr	11000			90		100		E	L	M	L	M
Pursuit Plus	Imazethapyr	11000			90		100		E	L	M	L	M
Pursuit Plus	Pendimethalin	0.275			90		5000			S	L	M	L
Pyramin	Pyrazon (Chloridazon)	400			21		120			M	M	M	S
Ramrod	Propachlor	613			6.3		80			S	M	M	S
Ramrod + Atrazine	Propachlor	613			6.3		80			S	M	M	S
Ramrod + Atrazine	Atrazine	33			60		100			L	M	L	M
Reflex	Fomesafen sodium salt	700000			100		60			L	M	L	M
Resolve	Dicamba	400000			14		2			L	S	M	S
Resolve	Imazethapyr	11000			90		100		E	L	M	L	M

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Resource	Flumiclorac	*			*		*			*	*	*	*
Rezult	Bentazon sodium salt	2300000			20		34			L	S	M	S
Rezult	Sethoxydim	4390	7		5		100		E	S	M	M	S
Rhomene	MCPA Dimethylamine salt	866000	7		25		20		E	L	S	M	S
Ro-Neet	Cycloate	95			30		430			M	M	L	S
Roundup Ultra	Glyphosate isopropylamine salt	900000		E	47		24000		E	S	L	L	L
Salute	Metribuzin	1220			40		60		E	L	M	L	S
Salute	Trifluralin	0.3			60		8000			S	L	M	L
Scepter	Imazaquin acid	60			90		20	7	E	L	S	L	M
Select	Clethodim	*			*		*			*	*	*	*
Sencor	Metribuzin	1220			40		60		E	L	M	L	S
Shotgun	2, 4-D ester	100		E	10		100		E	M	M	M	S
Shotgun	Atrazine	33			60		100			L	M	L	M
Sinbar	Terbacil	710			120		55	7		L	M	L	M
Solicam	Norflurazon	28			90		600			M	L	L	M
Sonalan	Ethalfluralin	0.3			60		4000			S	L	M	L
Spike	Tebuthiuron	2500			360		80			L	M	L	M
Squadron	Imazaquin ammonium salt	160000	7	E	60		20		E	L	S	L	M
Squadron	Pendimethalin	0.275			90		5000			S	L	M	L
Stinger	Clopyralid amine salt	300000		E	30		6			L	S	M	S
Storm	Aciflourfen sodium salt	250000			14		113		E	M	M	M	S
Storm	Bentazon sodium salt	2300000			20		34			L	S	M	S
Surflan	Oryzalin	2.5			20		600			S	M	M	S
Surpass	Acetochlor	*			*		*			*	*	*	*
Surpass 100	Acetochlor	*			*		*			*	*	*	*
Surpass 100	Atrazine	33			60		100			L	M	L	M
Sutan	Butylate	44			13		400			S	M	L	S
Sutan +	Butylate	44			13		400			S	M	L	S
Sutazine	Atrazine	33			60		100			L	M	L	M
Sutazine	Butylate	44			13		400			S	M	L	S

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Tandem	Tridiphane	1.8			28		5600			S	L	M	M
Thistrol	MCPB	200000		E	14		20		E	L	S	M	S
Tillam	Pebulate	100			14		430			S	M	M	S
Tiller	2, 4-D ester	100		E	10		100		E	M	M	M	S
Tiller	Fenoxaprop-ethyl	0.8			9		9490			S	L	M	M
Tiller	MCPA ester	5		E	25		1000		E	S	L	M	M
Tordon	Picloram salt	200000		E	90		16			L	S	L	M
Tough	Pyridate	*			*		*			*	*	*	*
Treficon	Trifluralin	0.3			60		8000			S	L	M	L
Tri-4	Trifluralin	0.3			60		8000			S	L	M	L
Tri-Scept	Imazaquin ammonium salt	160000	7	E	60		20		E	L	S	L	M
Tri-Scept	Trifluralin	0.3			60		8000			S	L	M	L
Trilin	Trifluralin	0.3			60		8000			S	L	M	L
Turbo	Metolachlor	530			90		200			L	M	L	M
Turbo	Metribuzin	1220			40		60		E	L	M	L	S
Velpar	Hexazinone	33000			90		54			L	M	L	M
Weedar 64	2, 4-D dimethylamine salt	796000			10		20			M	S	M	S
Weedone LV 4	Dichlorprop (2, 4-DP) ester	50		E	10		1000		E	S	M	M	
Weedmaster	2, 4-D dimethylamine salt	796000			10		20			M	S	M	S
Weedmaster	Dicamba	400000			14		2			L	S	M	S

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