# Popcorn
# Pest Management Strategic Plan
# for the North Central Region

**November 2002**

Information gathered on the
11th and 12th of March 2002
at a Workshop held at the
Allerton Crowne Plaza,
Chicago, Illinois

## Executive Summary

The need for a broad array of pesticides to support popcorn production was the theme that recurred throughout the development of this Strategic Pest Management Plan. Workshop participants agreed to address this in two ways; first, by seeking to maintain products that are currently registered and are safe and efficacious, and second, by working to include popcorn on the labels of newly registered products.

This need is clearly illustrated by the plight popcorn producers would face if further limitations were imposed on atrazine. Additional constraints on rates or application timing could result in the use of alternative products with undesirable characteristics including: poor weed control, crop injury, reduced grain quality, and a significant increase in production costs. The continuing availability of atrazine, which has a high degree of crop safety, is of critical importance to popcorn which is generally more susceptible to weeds and herbicide injury than is field corn. It is likewise important that new product labels include popcorn to permit growers to develop practices and procedures with newer chemistries that minimize the use of older compounds that may have health or environmental risks. Overall, this situation is not unlike any other where a full complement of tools is needed to complete the job; (i.e. although an axe can be substituted for a saw when building a house, it reduces efficiency, raises risks, and makes it difficult to produce a top quality product.)

Workshop participants indicated a closer relationship needs to be developed between the popcorn industry, the EPA, Land Grant universities, pesticide registrants, and the IR-4 program. As a first step in this process workshop participants agreed to meet with the EPA during the summer of 2002 to present the findings contained within this report and open a dialogue on registration issues. It is generally expected that an outcome of this meeting will be an improved communication network. The focus of that network will be to promote the objectives of maintaining and expanding pesticide labels for popcorn. A summary of the findings from that meeting will be presented to the Popcorn Board and circulated for comment.

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**Workshop Participants**

| | |
|---|---|
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**The Strategic Planning Process**

Much of the original intent of Pest Management Strategic Plans was to communicate to the US EPA detailed pest, pesticide, and pest management practice information. However, the role of these documents continues to expand, and Strategic Plans are now recognized as a means of providing an overview of pest management for production of a crop to a much broader audience. Not only do they communicate to the US EPA data relating to pesticides that are essential to economically viable crop production, but they also provide to the USDA, Land Grant Universities, and agri-chem industries, a prioritized list of issues that need to be addressed by research, education, or regulatory efforts. These Strategic Plans are also helpful to the agricultural industry as a means of evaluating progress on these issues. This document has been prepared to convey to the reader the pest management challenges confronting Midwestern popcorn producers. Though it is not all-inclusive, it is meant to be generally representative of popcorn production in the 12 states of the North Central Region. From time to time this document will be updated to reflect changes in pest management. If errors are discovered, please forward that information to one of the individuals listed at the end of this document.

This Popcorn Strategic Pest Management Plan was based on the Popcorn Commodity Profile which was first completed in 2001. Development of the Strategic Plan included modification of the information contained within the Profile to follow the format established by USDA for strategic plans. Once these changes were made the draft document was then further reviewed by agronomists who were familiar with popcorn production. On the 11th and 12th of March, 2002, a group of popcorn growers, agronomists, and University and agricultural specialists, met at the Allerton Crowne Plaza Hotel in Chicago to provide detailed comment on pests and pest control measures. At this meeting every pest and each pest control practice was evaluated for its impact on popcorn production. Those comments have been included within this document. Throughout this meeting attendees identified research, education and regulatory issues that popcorn producers also confront. Toward the end of the meeting each of these issues was presented in discussion for purposes of clarification. The final task of the meeting attendees was to prioritize the issues that they thought were the most critical to popcorn production in the Midwest. The list of prioritized issues immediately follows this page.

The growers and agronomists who met on the 11th and 12th of March, 2002, reached a consensus on those issues which were most important for popcorn production in general. These issues were given a priority of “A”. Second level priorities were given a “B” and third level a “C”. All other issues brought up during the meeting were assigned a “D” level of priority without further discussion. In general it can be assumed that number one “A” level priority is about twice as significant to producers as the number one “B” level priority, and so on.

**Popcorn Pest Management Top Priorities**
**Regulatory priorities:**

A 1 - Often, the modest market opportunity for a new product is insufficient to induce registrants to consider including a crop such as popcorn in their registration package. The registrants, the EPA and the FDA might explore means to streamline approval for popcorn or make it less expensive for registrants to include popcorn on labels. This might include grouping popcorn with other corn types where possible. This seems particularly applicable where similar grains have already received approval for human consumption. Unless there is reason to assume a difference in expected residues such grouping could provide for labeling a number of useful, and potentially less hazardous, pesticides.

A 2 - Maintaining the current atrazine registration for popcorn was considered a high priority. This herbicide is of critical importance to popcorn production due to lack of viable alternatives. The importance of atrazine as a convenient, effective herbicide that is safe to both humans and the crop should be communicated to the EPA and USDA.

A 3- Reducing the personal exposure level of phosphine from 0.3 ppm down to 0.01 ppm, is very difficult to do on a practical level. Means should be explored that would allow the continued use of this product in a safe manner, without jeopardizing shipment and commerce of popcorn.

B 1- Callisto (Syngenta) is currently registered for field, seed and sweet corn but has no specified use for popcorn. This product would appear to have a good fit with many of the weed control needs in popcorn and should be investigated for a popcorn label. The IR-4 program may play a role in addressing this issue.

B 2- Further removal of popcorn from OP insecticide labels could compromise popcorn production.

Where potential registered uses may be lost, the lost use should be carefully evaluated for its impact. (i.e. Lorsban, was kept on field corn but lost on popcorn) However, since lost registrations are inevitable, there is a critical need to evaluate and register products from other chemical families on popcorn, both seed treatments and over the top. These should include the neonicotinoid family; Actara, and Cruiser (thiamethoxam), Provado and Gaucho (imidacloprid).
C 1- Hybrid sensitivity to herbicides (carryover and direct injury from post application) is a critical issue. Where such information is known or can be determined by the registrant, hybrid sensitivity information should be communicated to popcorn seedsmen.
D1 - There is a lack of uniformity in organic popcorn production from state to state. Some effort needs to be made to unify the standards of production.
D2 - There is a great deal of inconsistency in the efficacy of pheromone products. (Esp. Western bean cutworm pheromone) Some effort should be made to provide standards for these products.

**Research priorities:**
A 1 - Research is needed to determine hybrid sensitivities to herbicides. IR-4 can play a role and both registrants and Land-Grant Universities are encouraged to address this issue. Though some of this information may be collected anecdotally from producers and agronomists, a more coordinated and concerted effort is needed.
A 2 - Research is needed to identify proper timing of fungicide applications on popcorn, especially for gray leaf spot. There is considerable futility in applying fungicides too late -(i.e. after seeing disease) and there is a need for determining when a disease may be present and when it may be appropriate to treat.
A 3- Research is needed on the potential for use of the Insect Growth Regulators (IGRs) in stored popcorn. There is a significant need for a product such as Di-con II, that could be used for Indian meal moth and other stored grain insect pests.
B 1 - Research is needed to determine the distribution and severity of mycotoxins in popcorn. Little is known regarding what mycotoxins are present, how they might be controlled, understanding mechanisms of infection (storage molds and mycotoxins that come with them), the use of diagnostic kits for detection, and managing moisture and other conditions in grain bins to minimize their impact.
B 2- The need for continuing plant breeding efforts for resistant hybrids for all diseases is a continuing priority. Conventional plant breeding and inbred development cannot be overlooked as a means of minimizing pesticide use and maximizing quality traits in popcorn.
C 1 - Research on giant ragweed control in popcorn is needed. Because the canopy in popcorn does not close as quickly as with field corn, several flushes of giant ragweed can occur during a season and be a serious problem for yield reductions and harvestability. It would be helpful to know the best approach to controlling this weed.
C 2- Research is needed to determine if insecticide rates could be lowered and still be effective? Many growers are currently using less than labeled product rates with good success, but the reliability of such low rates being broadly recommended is questioned.
C3 - Research is needed to evaluate the impact on popcorn production from the Western corn rootworm variant and the Northern corn rootworm with extended diapause traits. It would be helpful to have a method for predictive modeling of its economic impact.
C4 - Research is needed to evaluate the impact of soybean herbicide carryover for popcorn. Popcorn is more sensitive than field corn to many herbicides, but the label restrictions for planting popcorn in a rotation following soybean seems excessive for many herbicides.
D1 - Research is needed on alternate methods of resistance management for weeds. The current post emergence grass control products have crop injury that inhibits their use as resistance management tools.
D2 - Research is needed to deal with black nightshade, morningglory species, and other weeds after Roundup Ready soybeans. Weeds break through late in the soybean season and produce seed that becomes a problem for popcorn in the following year.
D3 - Research is needed on atrazine fate and dissipation to determine the adverse impact of current atrazine use levels.
D4 - Research is needed on the needle nematode, to include thresholds and economic impacts on yield and how to control.

D5 - Research is needed on the European Corn Borer (ECB) third generation, the univoltine biology and how it is changing, and the best control methods.
D6 - Research is needed on popcorn specific thresholds for ECB.
D7 - Research is needed on flea beetles, as they are becoming more of a concern with mild winters. We need to know threshold information as well as more about their role in Stewart's Wilt transmission, etc.
D8- Research is needed on the lesser grain borer. This insect seems to be moving north and it would be good to know if it will continue to do so and how quickly.
D9 - Research is needed on gray leaf spot. This disease is becoming more prevalent and more attention needs to be paid to it.
D10 - Research is needed on the epidemiology and basic background of ear rots so that control can better be effected.

**Education priorities:**
A 1- A regional manual on popcorn production and pest management is considered a high priority. This publication may be published in either a print version or on the web. It should include an updated Pest Management Manual as well as information for growers on water quality issues, atrazine stewardship, and similar environmental concerns.
B 1- It is important to educate registrants on the need to keep popcorn on pesticide labels whenever possible. It is important for the popcorn industry to regularly communicate to the registrants those uses that are deemed important.
C 1- Growers need to be educated on the proper timing of fungicide applications. (See Research priority above). Many fungicide applications are applied too late to be effective.
C 2- Growers and registrants should be educated on the potential for soybean herbicide carryover injury to popcorn. (Although much research needs to be done to better define appropriate intervals for popcorn rotation. -See Research priorities above).
D1 - Growers need to be better educated on weed resistance and how it develops.
D2 - Consumers need further education on the beneficial characteristics of GMO popcorn.
D3 - It should be communicated to the EPA that growers are making a good faith effort to use Best Management Practices that minimize ground water concerns with triazine herbicides. Growers are concerned about the potential loss of atrazine and will continue to exercise caution in their use of these products in an effort to keep atrazine registrations for popcorn.
D4 - Custom applicators need to better understand the differences between popcorn and field corn. Some custom applicators have not exercised sufficient care in setting the rates or in selecting non-injurious pesticides for popcorn, or in applying a pesticide to popcorn that does not have an existing tolerance for the crop.

# Popcorn

# Strategic Pest Management Plan

**Background:**
Popcorn *(Zea mays everta*) is a type of corn that has a very hard endosperm. The starches in the endosperm, when permeated with the right amount of moisture (13-14%), expands when heated and abruptly ruptures the tough outer covering (pericarp). Popcorn varieties, of which there are many commercial hybrids, have many different kernel colors, sizes, and shapes. The predominant types of popcorn include white corn, which typically has kernels with pointed ends (rice type), and yellow kernels of both small and large sizes that have more rounded kernels (pearl type). The type of popcorn grown by producers depends on the needs of the processor. The compact "mushroom" shape of some popped corn varieties is favored by processors who coat their products with caramel or cheese flavorings and pack the popped corn for shipment. The fine textured "butterfly" shape of other popped varieties is typically favored as a snack for at-home popping.

**Regional Production:**
Since the 1940s, popcorn production has centered in the upper Midwestern States. As open-pollinated varieties have given way to hybrids the number of acres of popcorn grown in the each state has shifted over the years. Currently Indiana and Nebraska are the major producing states. In 2000, approximately 210,000 acres of popcorn were planted. Of this amount, 95% was grown in the twelve states of the North Central Region. In 1999, the average yield was 4,000 lbs per acre. In the table below are figures indicating popcorn consumption for 1998, 1999, and 2000. In 2000, 230 million pounds of popcorn were consumed within the United States and Canada, or approximately 0.8 pounds per person per year.

**Table 1. Processed Popcorn Sold in the U.S. and Canada from 1998 through 2000 (Million pounds).**

| | 1998 | 1999 | 2000 |
|---|---|---|---|
| Domestic | 765 | 755 | 787 |
| Export | 128 | 142 | 150 |
| Totals | 893 | 897 | 937 |

**Markets and production economics:**
Producers can be classified as either contract or independent growers. Contract growers are producers who grow, maintain, and harvest a crop under contract with a processor. Many of these growers will have contracts every year or nearly every year. The size of the acreage grown under contract varies annually depending on the need of the market.

Independent growers face considerable risk in producing a crop, particularly if they have no fixed outlet or their product has not yet established name-brand recognition. If the market becomes saturated and prices fall the independent must dispose of the crop at whatever price can be obtained, or must store the grain until prices recover. Although popcorn not used for human consumption may be milled for animal feed, it yields less than field corn and does not produce a profit when so used. The large number of growers who have recently begun popcorn growing enterprises has depressed spot market prices and increased the financial risk for new growers.

Prices for popcorn grown under contract may be fixed at the initiation of the contract or tied to the price of other commodities. Although the retail price consumers pay for popcorn may suggest that this crop has a high profit margin, this is not true for most producers. (http://www.hort.purdue.edu/newcrop/afcm/popcorn.html)
The average recent contract price has been from 9 cents to 10.5 cents per pound. (See http://ohioline.ag.ohio-state.edu/~ohioline/e-budget/99popc.html)

Although only 15 to 20 percent of the total crop is exported annually, some areas target a high proportion of their crop to foreign markets. Typical yields range from 2500 to 5000 pounds per acre.

**Table 2. 1999 - 2000 Acreage Report for Popcorn in the North Central Region**

| | Acreage Planted | | Acreage Harvested | | Production | Purchased |
|---|---|---|---|---|---|---|
| STATE | 2000 | 1999 | 2000** | 1999 | 1999 | |
| | (Thousands) | | (Thousands) | | (Million pounds) | |
| Illinois | 31.4 | 37.8 | 31.4 | 37.8 | 139 | 0 |
| Indiana | 55.3 | 74.4 | 55.0 | 74.4 | 247 | 3.4 |
| Iowa | 13.5 | 15.3 | 13.5 | 15.2 | 47 | 0.1 |
| Kansas | 0.5 | 3.1 | 0.5 | 3.1 | 14 | 0 |
| Kentucky | 7.2 | 13.5 | 6.9 | 13.3 | 37 | 1.7 |
| Michigan | 0.6 | 0.7 | 0.6 | 0.7 | 3 | 0 |
| Missouri | 8.4 | 12.6 | 8.4 | 12.5 | 31 | 0.03 |
| Nebraska | 52.6 | 54.1 | 52.4 | 54.0 | 231 | 17.4 |
| Ohio | 36.2 | 28.2 | 36.1 | 28.2 | 103 | 0.3 |
| *Other | 5.2 | 8.0 | 5.2 | 8.0 | 26 | 2.8 |
| Total | 210.8 | 247.8 | 210.0 | 247.4 | 881 | 25.9 |

* Other: Alabama, Colorado, New Jersey, Maryland, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Virginia and Wisconsin.

** Expected harvest for 2000
This chart represents approximately 84% of the acres planted in the U.S.

**Production Practices**
**Planting, tillage, and fertilization:**

Popcorn production is similar to that of field corn in most ways and will thrive under similar conditions. The deep fertile soils, moderate rainfall and temperate weather of the Midwest are ideal for high yields and quality. Fields are generally fertilized at levels similar to field corn but are more likely to have starter fertilizer applied at planting and a side-dress application of nitrogen later in the season. Fields may be tilled prior to planting to reduce weed competition.

Fields are planted from 15 April, in the southern area of our region, to about the 25th of May in the northern areas. Seeding rates range from about 26,000 to 36,000 depending on the size of the seed and available moisture and irrigation. Average field size for popcorn produced under contract ranges from 30-240 acres. The range of acreage contracted per grower is typically 100-400 acres but may be as high as 1500 acres for a few select growers. Popcorn is generally planted with the same equipment as field corn. Popcorn is grown in rotation with many common Midwestern crops. Crops that most commonly precede popcorn in the year-to-year rotations include soybeans (50-80%), popcorn (10-15%), and other crops (5-25%)(alfalfa, wheat, pasture, vegetables).

Although tillage regimes vary across the Corn Belt, as much as 70-80% of the popcorn is planted no-till in Indiana and Ohio. No-till popcorn is less common in states further west. Row cultivation for weeds in popcorn is less common in the eastern region of the Corn Belt (10-25% of fields), but may be practiced on up the 75% of the acreage in western part of the region. Due to the poor drainage of some soils, tillage and/or field accessability may be greatly limited. As a result, row cultivation may not be a practical method of weed control in some fields.

Approximately 15% of all commercial popcorn fields are irrigated in the eastern area. It is estimated that more than 75% of the popcorn in Nebraska, Kansas, and South Dakota is irrigated.

**General pest control comments:**

Because most of the popcorn is produced using conservation tillage practices and popcorn is not very competitive with weeds, pre and post-emergence herbicides are heavily relied upon for weed control. Also, insect and disease control is considered very important because product appearance and cleanliness are directly related to product value.

Crop scouting is practiced on the majority of acres (90%). Although fields may be entered from 3 to 6 times per season for pest scouting, more intensive visits would improve proper scheduling of pesticide treatments.

**GMO comments:**

GMO plants and seeds have met great resistance world-wide. The perception that many consumers have is that GMO's are harmful and hence, popcorn hybrids with GMO traits have not yet been accepted by consumers. If consumers were to accept GMO popcorn, the Bt type hybrids could reduce or eliminate spraying pesticides for control of corn borers. It is also possible that Roundup Ready popcorn could reduce the risks of crop losses many growers now face should atrazine be cancelled. Research and education is needed to demonstrate that GMO plants and seeds can be safe to humans and the environment. The most important message that needs to be communicated is that unwanted chemicals in our water, soil, air, and food systems could be significantly reduced through the adoption of many GMO plants and seeds.

**Synthetic chemical free production:**

Although "organic" brand-name "gourmet" popcorn has grown considerably in market share within the last few years, the production of certified organic popcorn remains a small fraction of that popcorn which is conventionally produced. Close to 95% of the organically grown popcorn is scouted for pests and nearly all that is done by the grower or the grower's family.

**Harvest practices and yields:**

Popcorn is harvested when the kernels mature and have reached optimal moisture content. Harvest may take place during an extended period (mid-Sept to early Dec). Production of popcorn on a smaller acreage may employ manual labor for hand picking ears from the plant. Larger production systems will use mechanical means to harvest the ears.

**Pest Resistance Issues**

**Herbicides:**

Weed resistance to herbicides is now recognized as a major threat to popcorn production. Pre-emergence applications of atrazine followed by postemergence applications of atrazine are relatively common and can lead to the development of resistance. Common weed species that now have resistance to the triazine herbicides include common lambsquarters, giant foxtail, kochia, waterhemp, and redroot pigweed.

**Insecticides:**

Insect resistance development is of concern to popcorn producers. Corn borers are the pests that are of principal concern. Since lodging of the crop can produce a greater economic loss for popcorn than for field corn this crop is sprayed more often for this pest, increasing the likelihood of resistance development.

Corn rootworms adults in Nebraska have been documented to be resistant to organophosphates.

**Fungicides:**

No fungal resistance issues of significance are present that are not being addressed by hybrid improvements.

**Worker exposure Issues**

**Applicators/loaders**:

Approximately 90% of all herbicides applied to popcorn grown under contract are applied with sophisticated equipment bearing air filtration systems. It is estimated that an applicator operating a ground rig will take approximately one minute for each acre and for each pesticide application. This includes mixing, loading, and application, but not transit time to get to and from the fields. Each acre of contract popcorn receives approximately two herbicide applications per season. Applicators generally wear rubber gloves and goggles, and often masks, when mixing and loading sprayers or nurse tanks. The greatest amount of exposure to applicators will be to their face and arms.

Approximately 60 percent of popcorn fields are treated with a soil applied granular insecticide at planting whereas 100 percent of the "non-organic" popcorn fields are treated with a herbicide. Post-emergence insecticide use varies greatly from year to year but can be as low as 5 percent in the eastern portion of our region to as high as 100 percent in the western states in the region. Over 90% of the post-plant treatments are aerially applied or through irrigation where possible. Insecticides used on small fields of popcorn produced for roadside stands and farmer's markets are applied with a wide range of less sophisticated equipment. It is not known whether a small acreage, not under contract and grown for local markets, will have less frequent insecticide applications than acreage grown for contract.

During planting, growers handle bags of seed that have been treated with a fungicide. Planting operations will take approximately one day for each 100 acres of corn grown. During this time the planting boxes will be refilled an average of five times with approximately ten minutes of handling per refill. Leather gloves are usually worn during refill operations. Average number of days exposed to agri-chemicals during planting: 3 days.

Other workers exposed to pesticides include the applicator, handlers/loaders, planter operators, chemical delivery people, and the wives of workers who wash such clothes. Contact with pesticides may occur as a result of equipment maintenance and calibration, normal pesticide application, equipment clean-up, or spills. The risks associated with pesticide exposure to people handling popcorn is not expected to be greater than exposure estimated from field corn. The period of exposure to all agri-chemicals may be up to 45 days per year for the farmer, up to 90 days for applicators and warehouse workers, and 15 days per year for all others.

**Crop scouts**:

Some crop scouting takes place within 6 weeks of planting. During this period physical contact between the crop scout and pesticide residues on the soil or emerging crop is minimal. However, after this initial period some insect and disease scouting in standing corn is necessary. Good communication between the scout and the grower minimizes unnecessary or prohibitive contact with pesticide residues. In addition, many field scouts wear vinyl rain suits while in the fields due to the heavy dew that can occur. It is estimated that for every 40 acres of popcorn about three hours of in-field scouting per season is required. The individual doing the crop scouting will be in the field an average of four to six times during the season on contract crops and 3 times during the season for a small, non-contract acreage.

**Field workers:**

The availability of herbicides has reduced the need for hand hoeing or roguing. Hand hoeing does take place on very small production plots grown for roadside markets but this is probably also quite limited. For such small plots the total time spent hoeing or roguing is estimated at one hour for each acre.

**Harvesters**:

Contract fields of popcorn are harvested by machines and operators/handlers have little or no contact with the plant or the ears. Small plot acreage may be harvested by hand. This operation may involve the grower, his family, and other unskilled laborers. For every acre of popcorn harvested by hand approximately 8 hours of time is required in the field. Gloves made of soft leather or heavy cotton are usually worn when hand harvesting.

**Herbicides**:

Although applications of granular herbicides over the row is more common on small farms than it is on larger farms, it is estimated that even on small farms less than 5% of all herbicides are applied to popcorn in the granular formulation. Ninety-nine percent of the herbicides are applied by ground application equipment.

Many new herbicides are available as a dry formulation and are water-dispersable and have a reduced dust inhalation risk. Dry formulation packaging also has fewer container disposal problems. Exposure of either farmers or custom applicators during mixing and loading has not been well researched. We can speculate that the increase in use of pesticides that are available in highly concentrated dry formulations has great potential for reducing such exposure.

**Insecticides**:

For small fields, growers who apply their own insecticides may be at higher risk of exposure than growers of larger tracts who may have aerial applicators make such applications. Up to 80% percent of all post-plant insecticides are applied by aerial application or irrigation. These post-plant insecticides come in closed handling systems that result in little or no exposure to the aerial applicator. Soil insecticides are applied at planting by the grower. The approximate length of time to handle at-plant insecticides is roughly 10 minutes for every 10 acres of popcorn.

**Fungicides**:

Fungicidal seed treatments are used on 100% of all corn planted and consists of the same products as those used for field corn. Foliar fungicides are rarely used. For the small percentage of fields that are treated, growers who apply their own fungicides may be at higher risk of exposure.

**Post harvest handling**:

Post harvest exposure to latent pesticide residues may be an issue. Popcorn production on small acreage is graded, sorted, and packed by hand.

**Environmental Exposure Issues**

**General**:

Approximately 20 to 30 percent of all popcorn in the Midwest is produced on irrigated land, with as much as 75% of the popcorn in the western region of the Corn Belt under irrigation. Since irrigation in many parts of the Midwest is often on sandy soils, irrigated land may be at an increased risk for contamination by pesticides applied to popcorn. The location or edaphic conditions of the fields where non-irrigated popcorn is grown bears no distinction from other agronomic crops grown in the Midwest.

**Herbicides:**

Atrazine, a herbicide that has been found in ground and surface water, is widely used by most popcorn producers. The acetamide group of herbicides (alachlor, acetochlor, metolachlor, dimethenamid) are used on up to 90% of the popcorn in the region for preemergence grass control. They are known to contaminate water resources and can be a problem in areas with very shallow groundwater or high levels of soil erosion. Post emergence herbicides seldom cause an environmental concern.

**Insecticides:**

The use of soil applied insecticides may pose some risk to aquatic life in areas that experience soil erosion soon after application. Groundwater contamination may also be a concern in areas of sandy soils, high rainfall, or high water tables.

**Table 3. Pesticide Use on Popcorn (1999)**

| Pesticide | Brand Names | Percent treated | | Avg AI Rate Lbs/Acre | Target Pest |
|---|---|---|---|---|---|
| | | | | | |
| 2,4-D | 2,4-D | 17 | Post | .23 TO .47 | Brdlvs |
| Atrazine | Straight | 25 | Post | .85 TO 1.35 | Brdlvs/grass |
| | In premixes | 99 | Pre&post | | Brdlvs/grass |
| Nicosulfuron | Accent | 10 | Post | 0.15 | Grass |
| Dicamba | Banvel + Premixes | 10 | Post | | Brdlvs |
| Primisulturon | Beacon +Premixes | 36 | Post | | Brdlvs/grass |
| Metolachlor+Atraz | Bicep | 61 | Pre | 3.6 | Brdlvs/grass |
| Cyanazine | Bladex/Extrazine | 17 | Pre | | Brdlvs/grass |
| Bromoxynil | Buctril | 17 | Post | 0.75 | Brdlvs |
| Alachlor | Bullet/Lasso | 4 | Pre | 3.5 | Grass |
| Metolachlor | Dual | 11 | Pre | 2.2 | Grass |
| Dimethenamid +Atraz | Guardsman | 4 | Post | 2.04 | Brdlvs |
| Acetochlor | Harness + Premixes | 57 | Pre | | Brdlvs/grass |
| Bentazon + Atraz | Laddok | 5 | Post | 1.08 | Brdlvs |
| Simazine | Princep | 4 | Pre | 1 | Brdlvs/grass |
| | | | | | |
| Cyfluthrin+tebupirimfos | Aztec | 12 | Band at Plant | 0.15 | Corn Rw & Grubs |
| Terbufos | Counter | 20 | Band at Plant | 1.27 | Corn Rw & Grubs |
| Tefluthrin | Force | 41 | Band at Plant | 0.13 | Corn Rw & Grubs |
| Chlorethoxyfos | Fortress | 13 | Band at Plant | 0.48 | Corn Rw & Grubs |
| Chlropyrifos | Lorsban | 14 | Band at Plant | 1.2 | Corn Rw & Grubs |
| | | Some | Post | | ECB |
| Permethrin | Pounce | 3 | Post | 0.2 | ECB |
| Propaconazole | Tilt | 4 | Post | 0.05 | Grey Leafspot & Rust |

In addition to the above nearly all seed is treated with a fungicide seed treatment applied before planting. Treatments include fludioxonil, “Maxim”, or mefenoxam, “Apron and sometimes Captan.

**Registration Issues**
**Herbicides**:

Within the past few years actual losses of herbicide registrations, with the exception of cyanazine, have been few. However, restrictions have been placed on many herbicides in an effort to reduce contamination of surface and groundwaters. Atrazine, alachlor, cyanazine, and paraquat are all restricted-use pesticides. They may be purchased and applied only by or under the direction of certified, licensed applicators. Groundwater advisories have been added to many labels to prevent mixing, loading, and application in areas of high risk for runoff or leaching. Many additional restrictions have been placed on atrazine to limit its time, rate, and location of application to reduce contamination of surface and ground water resources. It is likely that additional restrictions will be imposed on individual products, to limit not only water contamination, but also drift, wildlife exposure, and residues in foods.

**Insecticides**:

The loss of carbofuran and the pending loss of methyl bromide are two issues of concern for insect control in popcorn. Methyl bromide as a stored grain fumigant is to be phased out by the end of 2004 and suitable alternatives must be in place prior to its loss. Carbofuran (Furadan 4F) has not been widely used as an insecticide on popcorn but its loss may be significant if other new chemistries are not identified for use on popcorn insects as a means of deterring insect resistance.

**Fungicides:**

None pending at time of writing.

**Critical Alternative issues**

It is recognized that for some commodities, non-chemical or organic methods of pest management may be employed. However, our intent is to focus on commercial popcorn production, which generally involves conventional pesticides. With this in mind, issues regarding retention of a specific pesticide or group of pesticides are given a rating of A, B, or C according to their level of significance to the commodity. Level A: product critical, alternatives are very limited in availability and scope, loss of product would cause regular and drastic changes in production, safety, or commodity price. Level B: product essential, alternatives limited in application, loss of product would cause significant changes in production, safety or commodity price. Level C: product fundamental, alternatives exist, loss of product would cause few changes in production, safety, or commodity price.

**Critical Herbicides:**

(Atrazine, level A,.) The most critical herbicide issue for popcorn production is the possible loss of atrazine. Atrazine is inexpensive, effective, has a wide window of application, and little to no crop injury. There is no alternative to atrazine that would provide similar utility. Most alternatives, although effective in providing weed control when applied properly, have a propensity for crop injury and have a much narrower window of application. Atrazine is very widely used and its loss would result in significant changes in production, most notably a reduction in popcorn acreage planted and a reduction in per acre yields, and hence a significant increase in cost of the product. Nicosulfuron, and the primisulfuron combination products of Spirit and Northstar, also have important uses as post applied, late-season "rescue" treatments. Good alternatives for these products are not available. This is especially true in areas where shattercane and Johnsongrass are abundant. (Level B) (All other individual herbicides, level C)

**Critical Insecticides:**

All insecticides used for stored grain insect control for popcorn can be considered a Level A issue. The loss of methyl bromide at the end of 2004, as well as the expected reduction in the personal exposure level of phosphine from .3ppm to .01ppm will create a critical situation for maintaining stored popcorn at top quality levels. All currently registered insecticides for rootworm control could be considered essential (Level B). This classification is assigned because pesticide manufacturers are unlikely to register new insecticides on a crop such as popcorn, which has a limited market opportunity for new products. The increased potential for resistance development for popcorn insects remains a continuing concern.
(All other individual insecticides, level C)

**Critical Fungicides:**

(Fludioxonil, "Maxim", or Mefenoxam, "Apron", level B, loss of both classed as Level A) are

widely used as seed treatments for popcorn. In contrast to field corn, popcorn hybrids are particularly vulnerable during germination. The protection afforded by these products can be critical in cool wet soils where pythium and phytophthora are more prevalent. Captan can be classified as an alternative to fludioxonil and mefenoxam but is less efficacious.
(All other fungicides, level C)

**Pipeline products**
**Herbicides**:
Axiom- flufenacet+metribuzin may receive possible registration in popcorn.

Callisto - Mesotrione is a post-emerge herbicide for corn. Callisto has excellent activity on small seed broadleaf weeds and excellent crop safety. Callisto is a new product from Sygenta, but there is currently no effort to label this product for popcorn.
**Insecticides**:
Nicotinoid seed treatments and fiproles would be useful for soil insect suppression and control. They were not registered for popcorn at the time of writing. Both the nicotinoids and fiproles would add insecticide classes to popcorn to reduce possibilities of insect resistance.
**Fungicides**:
Few fungicides are registered for use on popcorn and fewer still are being evaluated for use on this crop. Additional modes of action are needed for resistance management.
**Co-occurrence of Applications**
**Herbicides**:
Atrazine will be used primarily with a grass control herbicide such as metolachlor, alachlor, or dimethenamid. These latter products are seldom used in combination and are not often used sequentially on the same field (< 5% of crop).
**Insecticides:**
Very seldom is more than one product applied during a single treatment. At times, herbicides may be mixed with insecticides where the label permits and need requires.
**Fungicides:**
The application of more than one foliar fungicide during a season, either in a combination or sequential application, is very rare (< 1% of crop). The use of a combination of products to expand the efficacy of seed treatments is quite common (>50% of seed treated).

**Weeds**
Weeds are present in every field every year. The severity of the weed population is determined by local field management practices such as the previous crop, fall and spring tillage, crop rotation patterns, and herbicide use. The prevalence of specific weeds throughout the region is dependent upon soil type, rainfall and moisture, temperatures, and day-length for the region. Although losses from weeds in field corn can average from 3 to 7 percent annually, losses due to weeds in popcorn can be 15 percent or more.

Within this document weeds are grouped in logical categories for discussion purposes. Like many plant diseases, most weeds in the following categories can be classified as minor pests in corn production. However, unlike plant diseases that are held at bay by genetic breeding, the classification of these weeds as minor pests can only be done in light of the many registered herbicides that must continue to be available to the producer.

Annual species comprise a majority of the weeds found in popcorn production. Many of the primary weed species are introduced rather than native. Native and non-native plants become weeds because they are adapted to the crop rotation system used throughout the Midwest, germinate at or near the same time as the crop, and are able to produce seed before the crop is removed by harvest. Weeds reduce yield primarily by competing for water, sunlight and nutrients, thus diminishing total popcorn yield potential. Heavy weed infestations can also decrease harvest efficiency. Weeds also harbor insect and disease pests that can affect the quality and popability of popcorn as well.

Increases in conservation tillage practices have resulted in a greater prevalence of weeds from three different classes; perennial weeds (i.e. common milkweed, hemp dogbane, and morningglory family, etc), small seeded grass and broadleaf weeds that produce seeds able to germinate near the soil surface (i.e. fall panicum, lambsquarters, pigweeds, woolly cupgrass, etc), and winter annual weeds (i.e. common chickweed, henbit, and numerous mustards). In addition, weed species which have developed resistance to herbicides have in many cases become more prevalent (i.e. shattercane, giant foxtail, cocklebur, kochia, and lambsquarters). The most significant resistant weeds in recent years are the tall and common waterhemp species.

**Tillage Note**.

Primary tillage, including plowing, discing, and field cultivation, has varying degrees of efficacy on the weeds listed in this document. Where soil erosion and conservation practices allow, primary tillage can reduce the threat of many **perennial weeds** and may also help eliminate **winter annual weeds** from a field prior to planting. However, the advantage once realized by primary tillage is no longer as significant as it once was. Earlier planting (and the need to till fields much earlier) has reduced the impact of tillage on many warm season **perennials**, which stay dormant until soils warm up later in the season.

Regular primary tillage has a variable effect on most **summer annual weeds**. Where primary tillage is possible, some seeds are buried too deep for germination while other seeds, which were buried in previous seasons, are brought closer to the surface. Though weeds that have already germinated at the time tillage is performed will be killed, tillage may accelerate the warming of soils and enhance seed germination of many species. For this reason most tillage practices are combined with herbicide applications to maximize the impact on germinating weeds.

Secondary tillage, including row cultivation and rotary hoeing, are also used less often than in the past. Relative to herbicides, these practices generally control fewer weeds and are less reliable. Although they can and are used to augment herbicides, rain, wet soils, and fields too large to cover efficiently with a limited amount of equipment restrict their usefulness.

Fields with significant amounts of crop residues can interfere with cultivation and rotary hoeing and rain may prevent timely mechanized field operations. In addition, field corn may be seeded in narrow rows that can be difficult to navigate with a cultivator without damaging the crop's roots. When good soil conditions persist, 70 to 80 percent of the weeds between the crop rows may be removed by a single row cultivation. However, this is usually insufficient to prevent remaining weeds and later emerging weeds from causing yield reductions at harvest. The 20 to 30 percent of the weeds still in the field will slow harvesting operations and can result in grain contaminated with dirt, pollen, and toxic weed seeds. Though row cultivation and rotary hoeing are helpful in suppressing **summer annual weeds**, herbicides are often recommended to 'fill-in the gaps'.

**Note on Adjusting Planting and Harvest Dates:**

Generally it is not a practical matter to move planting or harvest dates enough to affect the management of weeds, insects, or diseases. In order to efficiently use manpower and equipment and take advantage of optimal soil conditions, planting must be done when the 'window of opportunity' presents itself. If it were possible, adjusting planting dates might change which insects or diseases become significant pests, but generally planting date has little effect on overall weed presence. Adjusting harvest dates is somewhat more practical, yet it too cannot be done without regard to the quality of the grain harvested. Leaving the grain in the field too long can permit molds and toxins to build up in the unharvested ear, while harvesting too early increases the level of moisture in the grain and complicates disease and insect prevention in storage.

**Herbicide Resistant Weeds**

A number of weed biotype populations have been identified as having resistance to one or more herbicide classes. Those which most commonly have been found are waterhemp, lambsquarters, kochia, and pigweeds. In addition, resistant biotypes of common ragweed, cocklebur, shattercane, velvetleaf and giant foxtail have been found in some areas. The herbicide modes of action that have resulted in the most rapid development of resistant populations include those which have been used with the greatest frequency for weed control in corn and soybeans. This would include the triazines (translocated photosynthetic inhibitors) and the ALS inhibitors (sulfonylureas and imadazilinones). There is considerable concern about the potential development of resistance to glyphosate as it also has become widely used within the last 5 years.

The difficulty in dealing with herbicide resistant weeds is often that the presence of such weeds necessitates the use of a more robust and more expensive approach to weed control. Since whole groups of compounds are no longer effective many individual products within those groups will no longer be efficacious. Control often rests on a strategy of crop rotation (to permit rotation of herbicides) and herbicide combinations.

The development of resistant weed biotypes can be delayed or postponed indefinitely through the proper selection of herbicides, tillage, and equipment and field sanitation.

**1. Summer Annual Grasses**

Summer annual grasses infest approximately 98% of all popcorn acres. Many of these are controlled with preemergence herbicide applications and tillage. While not as competitive as broadleaf weed species on a plant for plant basis, annual grasses can reduce crop yields when significant populations are present. This is particularly true in dry years, where competition for moisture early in the season can be critical for corn development. However, due to the ease with which grasses are usually controlled in most weed management programs, control of most grasses is typically of secondary concern to control of broadleaf weed species. This may not be the case where grasses which are difficult to control, such as woolly cupgrass and sandbur are present in dense stands.

1a. Foxtails (*Setaria* spp)

There are three important foxtail species: giant foxtail (Setaria faberi), yellow foxtail (Setaria glauca), and green foxtail (Setaria viridis). At least one of these species can be found in nearly any field in the North Central Region. While low populations cause little crop competition, because of seed production an unchecked population can quickly become a severe problem. A primary control method for foxtail spp. is the application of preemergence grass herbicides. These provide early season control, reducing early season competition with the crop.

1b. Woolly cupgrass (*Eriochloa villosa*)

Woolly cupgrass is a relatively new and potentially serious weed problem in the states from Illinois and Wisconsin across to Nebraska and South Dakota. Its spread has increased rapidly in the last 10 to 15 years. This annual grass weed demonstrates biological, biochemical, and morphological characteristics that make it economically damaging and adds to the difficulty in developing effective management strategies. Woolly cupgrass is a prolific seed producer. This seed tends to germinate earlier and at higher populations than other annual grass weeds. Woolly cupgrass has demonstrated tolerance to most herbicides commonly used for control of annual grasses in popcorn.

1c. Fall panicum (*Panicum dichotomiflorum*)

Fall panicum is a summer annual that grows best in warm, wet, fertile soils. The plant tillers profusely and in late August and September the tillers open and scatter hard-coated seeds. These seeds may remain viable for years, and fall panicum is most often a problem in reduced or no-till fields whose undisturbed soils are favorable for germination. Fall panicum has shown some resistance to atrazine, and is one of the most serious grass weeds in the region.

1d. Wild proso millet (*Panicum miliaceum*)

Wild proso millet is a summer annual that tends to be more common in areas where popcorn is grown with regularity.

1e. Barnyardgrass (*Echinochloa crusgalli*)

This summer annual germinates from 0 to 5 inches deep in the soil. The seeds remain viable for several years, and plants may emerge throughout the summer. Barnyardgrass is most troublesome in low, moist, warm areas.

1f. Field sandbur (*Cenchrus incertus* and *C. pauciflorus*)

Field sandbur is a summer annual weed common in sandy soils. The bur of field sandbur can contaminate popcorn and result in a drop in grain quality.

1g. Crabgrass spp. (*Digiteria* spp.)

A warm season grass most often troublesome in the southern region of the Corn Belt. The plants expand by rooting at the nodes. May be most severe during the late part of the growing season after herbicides have degraded and/or holes remain in the canopy. Tillage and row cultivation also help control.

**Pre-emergence control of annual grasses**: As noted in the following section, annual grass control is generally most easily achieved with pre-emergence herbicides. Four classes of herbicide active ingredients are used pre-emergence; triazines (simazine, atrazine), acetamides (alachlor, metolachlor, dimethenamid, and acetochlor), dinitroaniline (pendimethalin), and thiocarbamates (EPTC, and butylate). In addition, glyphosate is sometimes use as a burndown herbicide prior to plant, especially on no-till popcorn. Although registered for use, pendimethalin is seldom used on popcorn due to the potential for crop injury. EPTC and Butylate have decreased in use for corn and popcorn production due to increases in reduced tillage and other viable options.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section*

**Photosystem I inhibitor (Triazines)**

- ★ Inexpensive
- ★ Excellent crop safety
- ★ Readily available
- ★ Synergistic with many other herbicides
- ★ Low crop injury
- ★ Reliable
- ★ Good handling characteristics
- ★ Can be combined with many other herbicides and some insecticides
- ★ Good, long lasting residual control of many weeds
- ★ Carryover concern to rotational crops
- ★ Potential for contamination of nearby water
- ★ High potential for weed resistance development

Atrazine (Many, in Marksman, Laddok)

- ★ Extremely good for post emergence weed control especially when combined with other herbicides
- ★ Much experience with all formulations
- ★ Multiple formulations

Simazine (Princep)

- ★ Cost effective
- ★ Better grass control than atrazine
- ★ Used as an alternate to atrazine (rotation of chemicals)
- ★ Somewhat narrower spectrum of control than atrazine
- ★ Cannot be tank mixed with as many products as atrazine
- ★ More persistent than atrazine (more carryover concerns)
- ★ Not as available as atrazine in general

**Root/shoot inhibitor (Acetamides)**

- ★ Generally good crop safety (exc. Acetochlor, see below)
- ★ Good grass control
- ★ Likelihood of weed resistance exceedingly small
- ★ Good window of application prior to planting
- ★ Weed control is weather dependent,
- ★ Water contamination from runoff/leaching is a concern

Alachlor (Micro-tech)

Metolachlor (Dual II Mag)

Dimethenamid (Outlook)

Acetochlor (Harness/Surpass, in FulTime)

- ★ Crop safety can be variable depending on weather
- ★ FulTime, as a post treatment, is almost unusable due to potential crop injury

**Mitosis inhibitor (Dinitroanilines)**

Pendimethalin (Prowl/Pentagon)

- ★ Inexpensive
- ★ Likelihood of weed resistance development is low
- ★ Good grass and small seeded broadleaf weed control
- ★ Crop injury can occur
- ★ If replant is necessary popcorn cannot be replanted

**Bleaching**

Isoxaflutole (Balance)

- ★ Some propensity for crop injury

Mesotrione (Callisto)

- ★ New compound, relatively unknown

**Shoot inhibitor (Thiocarbamates)**

- ★ Excellent grass and small seeded broadleaf weed control
- ★ Likelihood of weed resistance development is low
- ★ Crop injury potential (yield suppression)
- ★ Requires mechanical incorporation (cannot use in no-till, some reduced till)
- ★ Weed tolerance resulting from enhanced (accelerated) biodegradation in some fields

EPTC (Eradicane)

Butylate (Sutan Plus)

**EPSP synthase inhibition**

Glyphosate (Roundup)

- ★ Broad spectrum
- ★ Low to moderate cost
- ★ Use is strictly for burndown of existing vegetation prior to planting and for spot application to localized troublesome weeds after emergence
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants

**Post-emergence control of grasses**: As noted above, most grass weed control in popcorn consists of pre-emergence herbicides. Although some nicosulfuron (Accent) is used, crop injury and application restrictions limit the utility of this very effective herbicide. Other post-emergence herbicides have such limited activity on grasses that their use is very minor.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section.*

**ALS inhibitors (Sulfonylureas)**

- ★ Easy to use
- ★ Crop injury potential
- ★ High potential for weed resistance development
- ★ Possible interaction with OP insecticides
- ★ Need to use drop nozzles during application to reduce crop injury
- ★ Cost is higher than most other herbicides

Nicosulfuron (Accent)

- ★ Excellent post grass control (sometimes no other alternative)
- ★ Crop injury potential (hybrid sensitivity)

Primisulfuron (Beacon, in NorthStar, in Exceed, in Spirit)

- ★ Primarily broadleaf weed control
- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control
- ★ Need to use drop nozzles during application to minimize injury potential

Halosulfuron (Permit)

- ★ Primarily broadleaf weed control

- ★ Poor grass weed control
- ★ Application timing is critical

**Other Pest Management Techniques:**

**Tillage**: (See Tillage Note in General weeds section)

**Adust Planting and Harvest Dates:** (See Planting and Harvest Date Note in General Weeds section)

**Pipeline Products:**

- ★ None

**Table 4. Control Ratings for Grass Weeds in Popcorn.**

| Blanks indicate that control of the pest is insufficient to warrant consideration for use. | Foxtails | Woolly Cupgrass | Fall Panicum | Wild proso millet | Barnyard grass | Sand-bur | Crab grass |
|---|---|---|---|---|---|---|---|
| Atrazine 90DF | F | | | F | G | | F |
| Princep-simazine | G | | F | | G | | F |
| Micro-Tech-alachlor | G | | G | | E | | E |
| Dual II Mag-metolachlor | G | F | E | | E | | E |
| Outlook -dimethenamid | G | F | E | F | G | | E |
| Surpass/Harness-acetochlor | G | G | E | G | E | | E |
| Prowl-pendimethalin | G | G | G | | E | | G |
| Eradicane/Sutan-EPTC& Butylate | E | G | E | G | E | F | E |
| Roundup-glyphosate (Burndown) | E | E | E | E | E | E | E |
| **POST** | | | | | | | |
| 2,4-D amine | | | | | | | |
| Clarity (dicamba) | | | | | | | |
| Accent (nicosulfuron) | G | G | G | G | E | G | |
| Beacon (primisulfuron) | | | F | | | | |
| Exceed/Spirit-(prosulfuron+primisulfuron) | | | | | | | |
| NorthStar-(primisulfuron+dicamba) | F | | | | | | |
| Permit (halosulfuron) | | | | | | | |
| Aim (carfentrazone) | | | | | | | |
| Atrazine+Oil | | F | | F | G | | F |
| Buctril-Contour (bromoxynil) | | | | | | | |
| Tough 5EC (pyridate) | | | | | | | |
| Marksman (dicamba+atrazine) | | | G | | | | |
| Basagran (bentazon) | | | | | | | |
| Laddok (atrazine+bentazon) | | | | | | | |
| Callisto (mesotrione) NOT LABELED | ? | ? | ? | ? | ? | ? | ? |
| Tillage | F | F | F | F | F | F | F |

**2. Shattercane, perennial grasses and nutsedges.**

Shattercane and perennial grasses were once a severe problem in corn production prior to herbicides and when pasture was a standard part of the crop rotation. With the introduction of effective herbicides and decline in pasture rotations, many of these weeds have declined in importance.

2a. Shattercane (*Sorghum bicolor*)

Shattercane is an annual grass that is found only in cultivated fields where it reseeds itself. Since all sorghums are members of the same species and can hybridize, shattercane is often found in greater populations were sorghums are grown widely (Nebraska and Kansas). It is more prevalent in the southern portion of the Corn Belt. Shattercane outcrosses with other sorghum types and is known for developing resistance to ALS type herbicides. The seeds of shattercane are about the same size as popcorn and can contaminate the grain, reducing grain quality.

2b. Johnsongrass (*Sorghum halepense*)

Johnsongrass is similar to shattercane in some respects. Johnsongrass produces large rhizomes that can be spread throughout the field making it difficult to contain and control. Johnsongrass is more common in the southern portions of the Corn Belt. The seeds of Johnsongrass are about the same size as popcorn and can contaminate the grain.

2c. Quackgrass (*Elytrigia repens*)

Quackgrass is a perennial grass that spreads by rhizomes. These rhizomes are effectively spread by tillage, increasing the scope of the population in a field. Tillage is an effective control by depleting food reserves and bringing rhizomes to the surface.

2d. Yellow Nutsedge (*Cyperus esculentus*)

Yellow nutsedge is a cause of some of the most severe perennial weed infestations and is quite serious across the region. It reproduces from tubers as the seed does not survive overwintering, and tubers can adapt to almost any soil type and conditions. Tubers germinate at depths of up to 12 inches and may remain viable for up to three years in many soils.

**Pre-emergence control of perennial grasses**: Pre-emergence herbicide control of shattercane, nutsedges, and perennial grasses is generally with the use of EPTC or butylate. In addition, nutsedge can be suppressed by the acetamide herbicides, especially acetochlor. Roundup can also be used if the grasses are present in the field and growing prior to planting or if the grasses are actively growing after the crop is removed. For quackgrass, nutsedge, and Johnsongrass, tillage is useful and perhaps necessary.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section.*

**Shoot inhibitor (Thiocarbamates)**

- ★ Excellent grass and small seeded broadleaf weed control
- ★ Likelihood of weed resistance development is low
- ★ Crop injury potential (yield suppression)
- ★ Requires mechanical incorporation (cannot use in no-till, some reduced till)
- ★ Weed tolerance resulting from enhanced (accelerated) biodegradation in some fields

EPTC (Eradicane)

Butylate (Sutan Plus)

**EPSP synthase inhibition**

Glyphosate (Roundup)

- ★ Broad spectrum
- ★ Low to moderate cost
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants

**Post-emergence control of shattercane, nutsedge and perennial grasses**: Post emergence shattercane and perennial grass control is generally achieved by the use of Accent, Beacon, Exceed or Spirit. As indicated below for the specific products the hazard for these chemicals is crop injury and an inability to use them where certain OP insecticides have been used on the crop. Nutsedge may be controlled by Permit or by the use of Basagran or Laddok.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section.*

**ALS inhibitors (Sulfonylureas)**

- ★ Easy to use
- ★ Crop injury potential
- ★ High potential for weed resistance development
- ★ Possible interaction with OP insecticides
- ★ Need to use drop nozzles during application to reduce crop injury
- ★ Cost is higher than most other herbicides

Nicosulfuron (Accent)

- ★ Excellent post grass control (sometimes no other alternative)
- ★ Crop injury potential (hybrid sensitivity)

Primisulfuron (Beacon, in NorthStar, in Exceed, in Spirit)

- ★ Primarily broadleaf weed control
- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control

Halosulfuron (Permit)

- ★ Primarily broadleaf weed control
- ★ Poor grass weed control
- ★ Application timing is critical

**Photosystem II inhibitors**

- ★ Effective on small weeds especially when used in combination with other herbicides

Pyridate (Tough)

- ★ Almost unusable in some situations due to crop injury concerns
- ★ Applicators must be extremely careful with sprayers using air-assist booms

**Other Pest Management Techniques:**

**Tillage**: (See Tillage Note in General weeds section)

**Adust Planting and Harvest Dates:** (See Planting and Harvest Date Note in General Weeds section

**Pipeline Products:**

- ★ None

**Table 5. Control Ratings for Shattercane, Yellow Nutsedge, Johnsongrass and Quackgrass.**

| | **Stattercane** | **Johnsongrass** | **Quackgrass** | **Nutsedge** |
|---|---|---|---|---|
| Atrazine 90DF | | | F | F |
| Princep-simazine | | | | |
| Micro-Tech-alachlor | | | | |
| Dual II Mag-metolachlor | | | | |
| Outlook -dimethenamid | | | | |
| Surpass/Harness-acetochlor | | | | F |
| Prowl-pendimethalin | | | | |
| Eradicane/Sutan-EPTC& Butylate | G | G | F | F |
| Roundup-glyphosate (Burndown) | G | G | G | G |
| **POST** | | | | |
| 2,4-D amine | | | | |
| Clarity-dicamba | | | | |
| Accent-nicosulfuron | E | F | G | |
| Beacon-primisulfuron | E | | | |
| Exceed/Spirit-prosulfuron+primisulfuron | E | F | F | |
| NorthStar-primisulfuron+dicamba | | | | |
| Permit-halosulfuron | | | | G |
| Aim-carfentrazone | ? | ? | ? | ? |
| Atrazine+Oil | | | F | |
| Buctril-Contour-bromoxynil | | | | |
| Tough 5EC-pyridate | G | G | G | F |
| Marksman-dicamba+atrazine | | | | |
| Basagran-bentazon | | | | G |
| Laddok (bentazon+atrazine) | | | | F |
| Callisto (mesotrione) NOT LABELED | | | | |
| Adjust Plant/harvest date | | | | |
| Tillage | | F | F | F |

Blanks within the table indicate that control of the pest is insufficient to warrant consideration for use.

**3. Annual broadleaf weeds**

3a. Eastern Black Nightshade (*Solanum ptycanthum*)

This summer annual can produce thousands of berries; each berry contains up to 50 seeds. While nightshade is generally not considered a serious pest in the Corn Belt, severe infestations in individual fields do occur. Tillage and row cultivation are effective for early, newly emerged seedlings. The juicy berries of nightshade can stain popcorn, reducing quality to the point where it may be unmarketable.

3b. Common Cocklebur (*Xanthium strumarium*)

Common cocklebur is a summer annual weed. Its seeds are spread by attaching to animal fur or by tillage or harvesting equipment. Cocklebur is a serious competitor for moisture. Cultivation, tillage, and mowing will all help control cocklebur establishment. At harvest, the cocklebur seeds can cause problems with grain flow in the combine and result in grain loss and damage.

3c. Common Lambsquarters (*Chenopodium album*)

Common lambsquarters produce numerous small seeds which germinate after an overwintering process. Optimal temperature for germination is 70F, but can germinate between 40 to 94, which suggests early germination capabilities. Survival is favored by rains that dilute or leach herbicides from the soil surface.

3d. Common Ragweed (*Ambrosia artemisiifolia*)

Common ragweed is a summer annual that is favored by moist soils and can be a serious problem in individual fields. Control of common ragweed with tillage or row cultivation is effective in controlling small seedlings.

3e. Giant Ragweed (*Ambrosia trifida*)

Wet weather favors giant ragweed, and this summer annual may be a severe problem in isolated fields. The seeds of giant ragweed may remain viable in the soil for several years. Small seedlings can be controlled with row cultivation and tillage. The seed of giant ragweed is about the same size as popcorn and can contaminate the grain, reducing grain quality.

3f. Jimsonweed (*Datura stramonium*)

Jimsonweed produces several hundred hard-coated seeds per plant that may remain viable in the soil for years. This summer annual grows best under warm temperatures and moist soils. Jimsonweed infestations harm soybean crops via competition for water, especially in dry years. The shade of its leaves in shorter crops increases yield loss due to decreased nutrient uptake. Jimsonweed also contains the alkaloids, atropine, hyoscyamine, and hyoscine, which are toxic. Even small amounts of jimsonweed can cause harvest problems.

3g. Kochia (*Kochia scoparia*)

Kochia is similar to common lambsquarters in many respects. It produces numerous small seeds and can germinate early in the season. Kochia has also developed resistance to a number of herbicides including triazines and ALS compounds. Although not distributed as widely as lambsquarters, kochia has been expanding from small infestations started along rail and road systems where seed has been carried in.

3h. Morningglories (*Ipomoea* spp.)

Tall morningglory and ivyleaf morningglory are the two major annual morningglory species found in the Corn Belt. The seeds of these summer annuals may survive for several years in soil. Infestations are most common in moist soils along river bottomland, but these plants can be found most anywhere in the state. Annual morningglories adapt to crops by vining about the crop, so shading by the canopy is not particularly successful in reducing growth. Newly emerged seedlings can be controlled by tillage and cultivation, but this may result in conditions that favor emergence by weeds deeper in the soil profile. After vines begin to twine about the stems of the crop, cultivation may not be as effective. The seed of most morningglory species is about the same size as popcorn and can contaminate the grain, reducing grain quality.

3i. Pennsylvania Smartweed (*Polygonum pensylvanicum*)

This summer annual grows best on wet soils and is widely distributed across the Midwest. Smartweed emerges early in the spring and can be a severe problem if tillage is delayed on wet soils, as seedbed preparation may result in transplanting larger plants rather than destroying them.

3j. Pigweeds (*Amaranthus retroflexus*, *A. hybridus*, *A. palmerii*, other)

Pigweeds are prolific seed producers, and one plant can produce over 100,000 seeds in one growing season. The seeds of this plant may remain viable for years. Pigweeds are a problem in no-till systems because undisturbed soils favor germination of the minuscule seeds, and the debris keeps the field moist and allows for extended germination. Other favorable germination locations are where excess nitrogen is available, and where no soil applied herbicides have been used. Localized populations of some biotypes of pigweed have shown triazine or acetolactate synthase (ALS)-inhibitor resistance.

3k. Velvetleaf (*Abutilon theophrasti*)

Velvetleaf is the most significant annual broadleaf weed in most corn production and is most damaging in the central part of the region. Velvetleaf is a serious competitor for moisture in drought conditions. Cultivation can somewhat control velvetleaf when used in the early season. The seed of velvetleaf is about the same size as popcorn and can contaminate the grain, reducing grain quality.

3l. Waterhemp (*Amaranthus tuberculatus* and *A. rudis*)

Common waterhemp is a native species and is a serious weed problem throughout the Corn Belt. Changes in agricultural practices that favor this weed include reductions in tillage, herbicide selection, simplified crop rotations, and recent weather patterns. There are also many indigenous factors that have contributed to the increase in common waterhemp populations. These include seedling emergence late in the growing season, high seed production and an ability to germinate from shallow soil depths. Control of common waterhemp has become increasingly difficult due to resistance to many common herbicides. Waterhemp has demonstrated cross-resistance to all herbicides with the ALS inhibition mode of action, as well as to triazine compounds.

**Pre-emergence control of annual broadleaf weeds**:

Broadleaf weeds germinate at soil depths from 1/8th of an inch to 3 or 4 inches. Seed size and dormancy are the controlling factors for when and where these seeds emerge. Large seeded broadleaf weeds have greater seed food reserves and can emerge from greater soil depths where moisture is less variable than near the soil surface. Soil applied herbicides need to be in place and evenly distributed throughout the top 1 to 2 inches of soil at the time of emergence for adequate uptake and maximum effect. Under conditions of high rainfall many pre-emergence herbicides may be too diluted or leached out of this soil zone and rendered ineffective for control of these weeds. Under very dry conditions, pre-emergence herbicides may not have been leached into the soil far enough to have the substantial contact necessary for weed death.

Other broadleaf weeds produce small seeds, such as pigweeds, lambsquarters, kochia, and nightshade. Many of these weeds germinate throughout the season in response to soil wetting provided by occasional rainfall. Pre-emergence herbicides that have short soil persistence may not adequately control the late flushes of germinating weeds.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section.*

**Photosystem I inhibitor (Triazines)**

- ★ Inexpensive
- ★ Excellent crop safety
- ★ Readily available
- ★ Synergistic with many other herbicides
- ★ Low crop injury
- ★ Reliable
- ★ Good handling characteristics
- ★ Can be combined with many other herbicides and some insecticides
- ★ Good long lasting residual control of many weeds
- ★ Carryover concern to rotational crops

- ★ Potential for contamination of nearby water
- ★ High potential for weed resistance development

Atrazine (Many, in Marksman, Laddok)

- ★ Extremely good for post emergence weed control especially when combined with other herbicides
- ★ High level of experience with all formulations
- ★ Multiple formulations

Simazine (Princep)

- ★ Cost effective
- ★ Better grass control than atrazine
- ★ Somewhat narrower spectrum of control than atrazine
- ★ Cannot be tank mixed with as many products as atrazine
- ★ More persistent than atrazine (more carryover concerns)
- ★ Not as available as atrazine in general

**Root/shoot inhibitor (Acetamides)**

- ★ Generally good crop safety (exc. Acetochlor, see below)
- ★ Good control of many small seeded broadleaf weeds and most grasses
- ★ Likelihood of weed resistance exceedingly small
- ★ Good window of application prior to planting
- ★ Weed control is weather dependent,
- ★ Water contamination from runoff/leaching is a concern

Alachlor (Micro-tech)

Metolachlor (Dual II Mag)

- ★ Lasts slightly longer than other acetamides

Dimethenamid (Outlook)

Acetochlor (Harness/Surpass, in FulTime)

- ★ Crop safety can be variable depending on weather
- ★ FulTime almost unusable due to potential crop injury

**Mitosis inhibitor (Dinitroanilines)**

Pendimethalin (Prowl/Pentagon)

- ★ Inexpensive
- ★ Likelihood of weed resistance development is low
- ★ Good grass and small seeded broadleaf weed control
- ★ Crop injury can occur
- ★ If replant is necessary popcorn can not be replanted

**Bleaching**

Isoxaflutole (Balance)

- ★ Some propensity for crop injury

Mesotrione (Callisto)

- ★ New compound, little known

**Shoot inhibitor (Thiocarbamates)**

- ★ Excellent grass and small seeded broadleaf weed control
- ★ Likelihood of weed resistance development is low
- ★ Crop injury potential (yield suppression)
- ★ Requires mechanical incorporation (cannot use in no-till, some reduced till)
- ★ Weed tolerance resulting from enhanced (accelerated) biodegradation in some fields

EPTC (Eradicane)

Butylate (Sutan Plus)

**EPSP synthase inhibition**

Glyphosate (Roundup)

- ★ Broad spectrum control of grass and broadleaf weeds (also perennials)
- ★ Good application window
- ★ Low to moderate cost
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants

**Post-emergence control of annual broadleaf weeds**:

As mentioned above, several flushes of broadleaf weeds can occur throughout the season. Although there are no post-emergence broadleaf herbicides with true "residual" activity some herbicides do provide a modicum of control through soil activity. These herbicides include post applications of Atrazine and dicamba. Though the trend for increasing use of post applied herbicides continues, concerns about crop injury and drift to off-target crops or plants remains a hindrance. A new product and new chemistry (for popcorn) is Callisto (mesotrione). Since it is not yet registered for popcorn there is little known of the advantages and disadvantages other than it has potential for broadleaf weed control. However, new chemistries are always welcome from the perspective of managing resistant weed development.

*For control ratings of each weed for each listed herbicide or non-chemical management practice see the table at the end of this section.*

**Growth Regulator**

- ★ Inexpensive
- ★ Broad spectrum of control of broadleaf weeds and some perennial broadleaf weeds
- ★ Potential for crop injury
- ★ Preharvest interval sometimes too short for effective use
- ★ Drift to adjacent crops and non-crop plants

2,4-D (Many)

Dicamba (Clarity, Banvel, in NorthStar, in Marksman)

- ★ Some residual activity in soil
- ★ Potential for brace root deformation under high temperature and humidity conditions

**ALS inhibitors (Sulfonylureas)**

- ★ Easy to use
- ★ Crop injury potential
- ★ High potential for weed resistance development
- ★ Possible interaction with OP insecticides
- ★ Need to use drop nozzles during application to reduce crop injury
- ★ Cost is higher than most other herbicides

Nicosulfuron (Accent)

- ★ Excellent post grass control (sometimes no other alternative)
- ★ Has good control of some broadleaf weeds
- ★ Crop injury potential (hybrid sensitivity)

Primisulfuron (Beacon, in NorthStar, in Exceed, in Spirit)

- ★ Primarily broadleaf weed control
- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control

Halosulfuron (Permit)

- ★ Very good control of some annual broadleaf weeds
- ★ Poor grass weed control
- ★ Application timing is critical

**PPO inhibitor**

Carfentrazone (Aim)

- ★ New product and new chemistry, advantages and disadvantages are mostly unknown at the time of this writing. However, new chemistries are always welcome from the perspective of managing resistant weed development.

**Photosystem II inhibitors**

- ★ Effective on small weeds especially when used in combination with other herbicides
- ★ Primarily for broadleaf weed control

Pyridate (Tough)

- ★ Almost unusable in some situations due to crop injury concerns
- ★ Applicators must be extremely careful with sprayers using air-assist booms

Bromoxynil (Buctril, in Buctril-Atrazine)

- ★ Moderate crop safety
- ★ Needs tank mixing with other products for acceptable activity on many weeds

Bentazon (Basagran, in Laddok)

- ★ Good crop safety

**Other Pest Management Techniques:**

**Tillage**: (See Tillage Note in General Weeds Section)

**Adust Planting and Harvest Dates:** (See Planting and Harvest Date Note in General Weeds section

**Pipeline Products:**

- ★ None

**Table 6. Annual Broadleaf Weed Control Ratings**

| | Morningglory | Bur cucumber | Common Cocklebur | Jimsonwee | Common Ragweed | Giant ragweed | Smartweed | Wild Sunflower | Velvetleaf | Pigweed Waterhemp | Lambs quarters | Kochia | Black Nightshade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Atrazine 90DF | G | F | G | E | E | F | E | F | F | E | G | G | G |
| Princep-simazine | | | | | F | | F | | | G | G | F | F |
| Micro-Tech-alachlor | | | | | F | | F | F | F | F | G | F | G |
| Dual II Mag-metolachlor | | | | | F | | F | F | F | F | G | F | G |
| Outlook -dimethenamid | | | | | F | | F | F | F | E | F | F | G |
| Surpass/Harness-acetochlor | | | F | F | E | | G | F | E | G | E | G | G |
| Prowl-pendimethalin | | | | | | | | | | G | F | | G |
| Eradicane/Sutan-EPTC& Butylate | G | | G | G | | | | | | G | F | F | F |
| Roundup-glyphosate (Burndown) | G | E | E | G | G | G | G | E | G | E | E | E | E |
| **POST** | | | | | | | | | | | | | |
| 2,4-D amine | E | | E | G | G | G | F | G | G | G | E | F | |
| Clarity-dicamba | G | G | | G | | F | G | | | G | | E | G |
| Accent-nicosulfuron | E | G | E | E | E | G | E | E | G | E | E | G | G |
| Beacon-primisulfuron | | F | G | G | G | G | G | G | F | G | | E | G |
| Exceed/Spirit-prosulfuron+primisulfuron | E | G | E | G | E | G | E | G | G | E | E | G | G |
| NorthStar-primisulfuron+dicamba | G | E | E | E | E | G | G | E | G | E | G | E | G |
| Permit-halosulfuron | E | F | E | E | E | | E | E | G | E | G | G | G |
| Aim-carfentrazone | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| Atrazine+Oil | G | F | E | E | E | G | E | G | E | G | G | G | G |
| Buctril-Contour-bromoxynil | | | G | G | F | | E | G | G | F | E | G | E |
| Tough 5EC-pyridate | G | | E | E | E | E | E | E | G | E | G | F | G |
| Marksman-dicamba+atrazine | | | G | G | | F | | G | | E | E | G | G |
| Basagran-(bentazon) | | | E | E | G | G | G | G | F | F | G | F | F |
| Laddok (bentazon+atrazine) | G | | E | E | G | G | G | G | E | G | G | G | G |
| Callisto (Mesotrione) not labeled | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| Adjust Plant/harvest date/ and Sanitation | | | | | | | | | | | | | |
| Tillage (preplant+cultivation or rotary hoe) | F | F | F | F | F | F | F | F | F | F | F | F | F |

Blanks within the table indicate that control of the pest is insufficient to warrant consideration for use.

**4. Perennial broadleaf weeds**

The occurrence of perennial broadleaf weeds is highly dependent on the tillage regime used in corn production. Since most perennial broadleaf weeds do not tolerate tillage, these weeds are more of a problem in reduced tillage and no-till operations. Once populations of perennial weeds have become established in a field they are nearly impossible to eradicate. Although sanitation measures may slow the spread of these weeds it will seldom prevent their movement or eventual establishment.

4a. Common Milkweed (*Asclepias syriaca* L.)

This perennial weed reproduces by seeds and adventitious buds that sprout from underground roots. Seedlings produce vegetative buds 18-21 days after germination, and seeds may remain viable for up to three years. Seeds may germinate from as deep as 2 inches in the soil, and undisturbed fields or fields with reduced tillage and moist soils are favored. Problems with common milkweed have been increasing due to the decrease in tillage and row cultivation.

4b. Canada thistle (*Cirsium arvense*)

Canada thistle is a perennial weed with a vigorous, creeping root system. Propagation is by rootstock and seeds; only female plants produce seed. Preplant tillage and row cultivation can control small seedlings but are less effective in controlling plants arising from rootstocks.

4c. Field bindweed (*Convolvulus arvensis*) and hedge bindweed (Calystegia sepium)

These weeds are vining weeds commonly found in both cultivated and no-till fields. These weeds can rapidly engulf popcorn rows in vines reducing corn growth and yield. The extensive mass of vines also makes harvest very difficult. The seed of bindweeds is about the same size as popcorn and can contaminate the grain, reducing grain quality.

4d. Hemp dogbane (*Apocynum cannabinum*)

This perennial weed is capable of regrowth from perennating rootstock within six weeks of emergence. The underground root system may extend laterally 20 feet per year and downward as far as 14 feet. The central portion of the Corn Belt is usually most severely infested with dogbane. Tillage can reduce dogbane infestations, but is ineffective once populations are established.

4e. Swamp smartweed (*Polygonum coccineum*)

Swamp smartweed is commonly found in low, wet areas of fields. Because of an extensive root system it is a strong competitor with corn and difficult to eradicate. Because of it's similarity to Pennsylvania smartweed, an annual, many producers incorrectly identify this weed.

4f. Bigroot Morningglory (*Ipomoea pandurata*)

Bigroot morningglory is becoming more common. It produces a tuber that can reach eight inches in diameter and several feet deep. When the new vines emerge they are purplish in color. Control almost invariably will require many repeated treatments. The seed of bigroot morningglory is about the same size as popcorn and can contaminate the grain, reducing grain quality.

**Pre and Post emergence control of perennial broadleaf weeds**: As no-till and minimum till become more popular perennial weeds become more common. While many of the same herbicides for perennial weed control in field corn are available for popcorn, the lower tolerance of popcorn for injury from these herbicides or herbicide combinations make it more challenging to effectively control these weeds. Therefore, much of the effort to control perennial weeds takes place before the crop is planted or after it has been harvested. The control ratings for some of the more common perennial broadleaf weeds are included in a table at the end of this section. Other broadleaf weeds, such as pokeweed, hedge bindweed, and Jerusalem artichoke may also be present in some fields, but are less prevalent.

The control ratings given below for perennial weeds tend to be more subjective than those for annual weeds. For example, although a rating of “Good” for control of an annual weed typically suggests 85 percent or better control of a weed, a rating of “Good” for perennial weeds might indicate anywhere from 60% to 90% dieback. The variability in rating perennial weeds arises as a result of the fact that they are fewer studies to determine control, there are fewer products and control measures available with which to compare, and that perennial weeds typically re-sprout from root stock soon after dieback. It is generally agreed that multiple treatments in a season, that include a combination of herbicides and mechanical means of control, are necessary to reduce perennial weed populations and obtain what is otherwise termed "Good" control.

**EPSP synthase inhibition**

Glyphosate (Roundup)

Fair for common milkweed control, hemp dogbane, and swamp smartweed

Good for Canada thistle and field bindweed control

- ★ Broad spectrum
- ★ Low to moderate cost
- ★ Good control of all perennials but retreatment is necessary
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants

**Growth Regulator**

- ★ Inexpensive
- ★ Broad spectrum, (controls more than perennials)
- ★ Potential for crop injury, especially when mixed with other growth regulator
- ★ Preharvest interval sometimes too short for effective use
- ★ Drift injury potential to adjacent crops and non-crop plants

2,4-D (Many)

- ★ The ester formulation is particularly effective on perennial weeds but can cause additional concern with drift
- ★ Canada thistle (Fair), Field Bindweed (Good), and morningglory family (Fair).
- ★ It can also be used to accelerate the uptake of glyphosate for improved control of other broadleaf perennial weeds.

Dicamba (Clarity, Banvel, in NorthStar, in Marksman)

- ★ Some residual activity in soil for annuals
- ★ Good on Canada thistle and field bindweed
- ★ Potential for brace root injury under high temperature and humidity conditions

**Photosystem II inhibitors**

Bentazon (Basagran, in Laddok)

- ★ Effective on Canada thistle (Good)
- ★ Good crop safety

**Other Pest Management Techniques:**

**Adust Planting and Harvest Dates:** (See Planting and Harvest Date Note in General Weeds section

**Tillage**

- ★ Can be quite effective if planting is delayed until early sprouting occurs, although multiple deep tillage events may be required.
- ★ The soil erosion that results from tillage may preclude its use on many soils
- ★ Timing is critical, if done improperly tillage may result in the spread of rhizomes or root stock and proliferate the problem.
- ★ Also See Tillage Note in General Weeds Section

**Pipeline Products:**

- ★ None

**5. Winter Annual Weeds and Cover Crops**

A number of winter annual weeds can be present in fields throughout the Midwest with the most common of these being henbit and chickweed. Some winter annuals are more prevalent across the northern portion of the region, while others such as bluegrass and bromegrass tend to be more of a problem across the southern section of Missouri, Illinois, Indiana and Ohio.

Winter annual weeds start their growth in the fall and complete their life cycle in the spring, often bearing seed in May or June. While discing, plowing, or field cultivation tillage is effective for all winter annuals, no-till and conservation tillage fields must rely on herbicides for control. Heavy populations of winter annual weeds can sap the moisture from the soil and slow or reduce germination of the crop. Additionally, weeds present in the field early in the season may attract damaging insects and provide an environment for egg laying.

**5a. Common Chickweed** (*Stellaria media*)

A common weed which produces prolific amounts of seed and a thick mat of low vegetative growth. Can remove much soil moisture and, if untreated, can seriously affect crop establishment and growth in dry years.

**5b. Horseweed (Marestail)** (*Conyza canadensis*)(previously *Erigeron canadensis*)

This weed is becoming much more common throughout the Midwest due to reduced tillage. It produces a large amount of seed which is wind borne. Resistant biotypes of this weed to glyphosate have been identified.

**5c. Henbit** (*Lamium amplexicaule*)

This plant is a low growing (5 to 9 inches) winter annual. It can produce a thick mat of growth early in the season and pull needed moisture from the soil.

**5d. Mustards**

Mustard species include field pennycress (*Thlaspi arvense*), wild mustard (*Brassica kaber*), tansy mustard (*Descurainia pinnata*), shepherd's purse (*Capsella bursa-pastoris*), yellow rocket (*Barbarea vulgaris*), and the pepperweeds (*Lepidium* spp.) Although a number of herbicides may control some mustard species, the presence of mature (large) mustards in the fields early in the season often limits which herbicides may be applied. Though usually less aggressive than henbit and common chickweed in terms of population expansion, they are serious competitors with crops.

**5e. Brome grasses** (*Bromus* spp.)

Brome grasses include downy brome, Japanese brome, and cheat. If left uncontrolled these grasses will continue to pose a competitive threat to the crop throughout the season.

**5f. Bluegrass** (*Poa annua*)

Bluegrass can become more of a problem under continuous no-till. Though populations do not grow at an explosive rate control without tillage can be difficult.

**5g. Grass Cover Crops**

Grass cover crops include winter annual grains planted to protect the soil and build soil tilth and at time more established sods from conservation plantings being converted to cropland. The former may include barley, rye, and wheat while the latter may include ryegrass, orchardgrass, perennial bromegrasses, fescue and timothy.

**5h. Legume cover crops**

Alfalfa, clovers, and vetches are typically used as cover crops or as part of a forage mix with grasses in conservation plantings that are being converted to cropland. Where forage mixes are present a broad spectrum herbicide, or a tank mix of two herbicides capable of killing both the grass and the legume, will be necessary for control.

**Table 7. Winter Annual Weed Control Ratings**

| Pre-plant Burndown | Chick-weed | Horse-weed | Henbit | Mustards | Brome grass | Blue-grass | Grass cover crop | Legumes |
|---|---|---|---|---|---|---|---|---|
| Glyphosate | G | F | F | G | G | G | G | G |
| 2,4-D Ester | | G | | G | | | | F-G |
| Paraquat | G | | G | F | | | | |
| Atrazine | E | G | E | E | | G | F | |
| Dicamba | E | F | F | F | | | | G |
| Isoxaflutol | G | | F | G | | | | |
| Tillage (Primary) | G | G | G | G | G | G | F | |

**Chemical Control**

★ The herbicides and tillage listed in Table 7 are the principal methods used to control winter annual weeds. All of the listed control practices must be applied before the crop is planted to effectively control these weeds. Though some additional products are registered for such use, the majority of current treatments usually consist of a combination of tillage and herbicides or a mixture of two or more herbicides. Atrazine, in particular, is combined with other herbicides and will provide a synergistic effect when applied for weed control. In addition, atrazine is sufficiently persistent to control many summer annual weeds that germinate through the first few weeks after planting the crop.

**Photosystem I inhibitor (Triazines)**

Atrazine (Many, in Marksman, Laddok)

- ★ Inexpensive
- ★ Excellent crop safety
- ★ Readily available
- ★ Synergistic with many other herbicides
- ★ Low crop injury
- ★ Reliable
- ★ Good handling characteristics
- ★ Can be combined with many other herbicides and some insecticides
- ★ Good long lasting residual control of many weeds
- ★ Carryover concern to follow crops
- ★ Potential for contamination of nearby water
- ★ High potential for weed resistance development
- ★ Extremely good for post emergence weed control especially when combined with other herbicides
- ★ Much experience with all formulations
- ★ Multiple formulations

**EPSP synthase inhibition**

Glyphosate (Roundup)

- ★ Broad spectrum
- ★ Low to moderate cost
- ★ Good control of all perennials but retreatment is necessary
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants

**Growth Regulator**

- ★ Inexpensive
- ★ Broad spectrum, (controls more than perennials)

- ★ Potential for crop injury, especially when mixed with other growth regulator
- ★ Preharvest interval sometimes too short for effective use
- ★ Drift injury potential to adjacent crops and non-crop plants

2,4-D (Many)

- ★ The ester formulation is particularly effective for perennials but can cause additional concern with drift
- ★ It can also be used to accelerate the uptake of glyphosate for improved control of other broadleaf perennial weeds.

Dicamba (Clarity, Banvel, in NorthStar, in Marksman)

- ★ Some residual activity in soil for annuals
- ★ Good on Canada thistle and field bindweed
- ★ Potential for brace root injury under high temperature and humidity conditions

**Photosystem II inhibitors**

Paraquat (Gramoxone)

- ★ Effective on small weeds especially when used in combination with other herbicides
- ★ Very toxic
- ★ Applicators must be extremely careful of drift with sprayers using air-assist booms

**Bleaching**

Isoxaflutole (Balance)

- ★ Some propensity for crop injury

**Table 8. Average Crop Loss and Percent Crop Area Infested by Weeds** (Data provided by popcorn agronomists, 2001)

| **Weed Name** | **Scientific Name** | **% Acres Infested** at any level | **% Loss on area infested** at current level of treatment | **Avg Loss%** |
|---|---|---|---|---|
| Barnyardgrass | *Echinochloa crusgalli* | 15 | 4.5% | 0.675 |
| Eastern black nightshade | *Solanum ptycanthum* | 30 | 0.7% | 0.21 |
| Common cocklebur | *Xanthium strumarium* | 50 | 0.5% | 0.25 |
| Common lambsquarters | *Chenopodium album* | 90 | 1.8% | 1.62 |
| Common milkweed | *Asclepias syrica L.* | 10 | 11.9% | 1.19 |
| Common ragweed | *Ambrosia artemisifolia* | 60 | 0.5% | 0.3 |
| Crabgrass | *Digiteria spp.* | 60 | 0.5% | 0.3 |
| Fall panicum | *Panicum dichotomiflorum* | 60 | 3.2% | 1.92 |
| Foxtails | *Setaria spp.* | 95 | 0.6% | 0.57 |
| Giant ragweed | *Ambrosia trifida* | 70 | 5.2% | 3.64 |
| Jimsonweed | *Datura stramonium* | 40 | 0.5% | 0.2 |
| Morningglory | *Ipomoea spp.* | 40 | 0.5% | 0.2 |
| Pigweed spp. | *Amaranthus spp.* | 90 | 0.5% | 0.45 |
| Shattercane | *Sorghum bicolor* | 20 | 1.1% | 0.22 |
| Velvetleaf | *Abutilon theophrasti* | 60 | 5.6% | 3.36 |
| Wild Proso Millet | *Panicum miliaceum* | 30 | 2.5% | 0.75 |
| All Weeds | | | | 15.855 |

## Insect Pests

Insect pests throughout the region can be classified as major or minor. The insect species are listed chronologically according to stage of popcorn development with a brief narrative detailing their effects and remedies.

Whether insect control measures are used, and which treatments are selected, depends greatly on the economics of popcorn production. Low popcorn prices and/or the failure to recognize that a pest is doing significant damage to the crop reduce the producer's inclination to treat for pests. Producers also select insecticides in expectation of controlling multiple pests in the same field, or a later emerging insect that may be expected to occur soon after the original target pest has been identified. In such situations, insecticides may not be selected for their specificity to one insect, but more for its ability to control two or more insects within a complex.

Most producers now have a basic understanding of how unwise use of insecticides can induce resistance in insect populations. The wide range of management options available to producers has permitted them to minimize insect resistance. However, the recent appearance of corn rootworms, which have developed methods of circumventing the cultural practices that have traditionally been used for their control (tillage/crop rotation), is a cause for much concern. It is evident that more needs to be done to determine a 'systems' approach to these pests and then educate producers and applicators on the proper choices and techniques for managing the development of resistance.

Though there appears to be a sufficient number of insecticide products and insecticide classes available for most major corn pests, it is deemed essential that this wide selection of products continue to be available to producers for this very reason (i.e. to provide a backstop for resistance management programs). It is also important to understand that many of the following insect pests, though classified as 'moderate' or 'minor' importance to popcorn production, can be very serious pests in localized areas, and may become more of a problem in larger areas as practices change or shift. Without effective insecticides for control of insect outbreaks, farms, communities, and entire regions of some states may suffer severe economic losses.

**Insects of germination, emergence**

**1. Seedcorn maggot** (Anthomyiidae)

- The seedcorn maggot is the larva of a small fly. The flies are attracted to fields where relatively fresh animal manure and other organic material is present. Seedcorn maggots seek out germinating soybean and corn seeds and eat the germ, killing the plant.
- Rescue treatments are not available for control of seedcorn maggot, therefore most treatments are made in anticipation of problems or replant situations.
- Soil moisture and temperatures are important contributing factors to infestations, but overall, seedcorn maggots are considered a minor pest in corn production.

**Seed Treatments**

**Organophosphate + Organochlorine**

Lindane+diazinon (Agrox DL) as a seed box treatment

★ Control = Fair
★ Inexpensive
★ Can be applied by grower
★ Application may not be uniform
★ Lindane can be phytotoxic
★ Exposure is a concern, allergies to dust

**Pyrethroids**

Permethrin (Kernel Guard Supreme) seed treatment

★ Control= Fair
★ Inexpensive
★ Can be applied to seed by grower
★ Application may not be uniform
★ Exposure during planter box fill is a concern

**Treatments to soil**.

**Organophosphate**

Terbufos (Counter)

- ★ Control =Good
- ★ Long life
- ★ Cost effective
- ★ Somewhat systemic
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control
- ★ Under cool, moist conditions and high pH may break down quickly
- ★ Use restrictions with some herbicides
- ★ Unpleasant to work with
- ★ Residue levels sometimes unpredictable
- ★ Concern of possible contamination of water supplies
- ★ REI= 48 hours or up to 72 hours in areas where average rainfall is less than 25 inches per year
- ★ Dry conditions tend to reduce control
- ★ More toxic (environmental and human) than other controls

Chlorethoxyfos (Fortress)

- ★ Control = Good
- ★ 5G formulation applied with Smartbox, reduces worker exposure
- ★ Smartbox pulsation causes erratic application of product
- ★ REI =48 hours

**Organophosphate + Pyrethroid**

Tebupirimphos+cyfluthrin (Aztec)

- ★ Control=Good to Excellent
- ★ Good formulation
- ★ Has performed well in efficacy trials on corn rootworm
- ★ Good longevity
- ★ Smart Box reduces worker exposure
- ★ Has good cutworm activity (pyrethroid)
- ★ Possible reduced rate usage
- ★ REI=0 hours

**Carbamates**

Carbofuran (Furadan)

- ★ Control =Fair to Good
- ★ Inconsistent performance
- ★ Liquid formulation only
- ★ Fields need to be posted for Worker Protection Standards (WPS)
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Tefluthrin (Force ST)

- ★ Control =Good
- ★ Mode of action permits use for resistance management
- ★ Reduced active ingredient per acre compared to granular formulation
- ★ REI = 0 hours
- ★ Reliable performance in trials and field
- ★ Less toxic than some alternatives
- ★ Skin sensitivity

Tefluthrin (Force 3G)

- ★ Control = Good
- ★ Mode of action permits use as resistance management tool
- ★ Reliable performance in trials and field
- ★ Also has good cutworm activity
- ★ Less toxic than some alternatives
- ★ Skin sensitivity

Bifenthrin (Capture)

- ★ Control = Fair
- ★ Can be applied through irrigation
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Cannot be used in no-till or reduced till

**Adjust plant/harvest dates**

- ★ Control = Fair
- ★ Cannot always delay planting as it may reduce yields or prevent planting altogether if late rains keep fields wet.

**2. True white grub** [*Phyllophaga* sp.], **wireworm** [*Melanotus* sp.], **Japanese beetle, annual white grubs, grape colaspis**

- These insects attack the germinating seed, newly emerging shoot, or feed on roots. Generally, infestations are patchy in fields and, depending on species, damage may recur in succeeding years.
- Rescue treatments are not available for control of these pests, therefore most treatments are made in anticipation of problems or replant situations.
- These pests are of moderate importance to corn production though they are becoming more prevalent as a result of reduced tillage
- White grubs tend to be more problematic in earlier planted corn.

**Treatments to soil**.

**Organophosphate**

Terbufos (Counter) Applied to furrow

- ★ Control = Good
- ★ Long life
- ★ Cost effective
- ★ Somewhat systemic
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control
- ★ Under cool, moist conditions and high pH may break down quickly
- ★ Use restrictions with some herbicides
- ★ Unpleasant to work with
- ★ Residue levels sometimes unpredictable
- ★ Concern of possible contamination of water supplies
- ★ REI= 48 hours or up to 72 hours in areas where average rainfall is less than 25 inches per year
- ★ Dry conditions tend to reduce control
- ★ More toxic (environmental and human) than other controls

Chlorethoxyfos (Fortress)

- ★ Control=Good
- ★ 5G formulation with Smartbox reduces worker exposure
- ★ Smartbox pulsation causes erratic application of product
- ★ REI = 48 hours

**Pyrethroids**

Tefluthrin (Force 3G)

- ★ Control =Good
- ★ Mode of action permits use for resistance management
- ★ REI = 0 hours
- ★ Reliable performance in trials and field
- ★ Also has good cutworm activity (pyrethroid)

- ★ Less toxic than some alternatives
- ★ Possible reduced rate use for insect control
- ★ Skin sensitivity

Bifenthrin (Capture)

- ★ Control= Fair to good
- ★ Can be applied through irrigation
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Tillage**

- ★ Not effective for these insects

**Adjusting Planting/Harvesting dates**

- ★ Avoid extremely early planting to reduce insect damage

**Vegetative Stages**

**3. Black cutworm** [*Agrotis ipsilon* (Hufnagel)]

- Black cutworm (BCW) is an insect that causes stand losses to young popcorn in the first month of growth. BCWs do not overwinter in the north central states. Southerly winds carry moths north from overwintering areas along the Gulf of Mexico, and mated females lay their eggs in fields. The moths seem to prefer weedy areas and plant residue to lay eggs, but can lay them in any field. Prophylactic treatments are not recommended because of the sporadic nature of the infestation patterns and intensities.
- In northern regions, tillage or burn down herbicides applied at least two weeks before planting greatly reduces damage by this pest.
- Sporadic pest with catastrophic results when it occurs, occurs more frequently in the southern growing areas of the region, and should be considered a pest of significant importance.
- Scouting is recommended and thresholds have been developed.

**Treatments to soil.**
**Organophosphate**

Terbufos (Counter)

- ★ Control= Poor
- ★ Long life
- ★ Cost effective
- ★ Somewhat systemic
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control
- ★ Under cool, moist conditions and high pH may break down quickly
- ★ Use restrictions with some herbicides
- ★ Unpleasant to work with
- ★ Concern of possible contamination of water supplies
- ★ REI= 48 hours or up to 72 hours in areas where average rainfall is less than 25 inches per year
- ★ Dry conditions tend to reduce control
- ★ More toxic (environmental and human) than other controls

**Organophosphate + Pyrethroid**

Tebupirimphos+cyfluthrin (Aztec)

- ★ Control=Fair
- ★ Good formulation
- ★ Good longevity
- ★ Smart Box reduces worker exposure
- ★ Possible reduced rate usage
- ★ REI=0 hours

**Carbamates**

Carbaryl (Sevin XLR)

- ★ Control=Good
- ★ Inexpensive
- ★ XLR formulation is long lasting
- ★ Low toxicity to humans
- ★ Treated fields need to be posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI= 48 days

Carbofuran (Furadan)

- ★ Control=Good
- ★ Inconsistent performance
- ★ Liquid formulation only
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control=Excellent
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ REI=12 hours
- ★ PHI=21 days

Tefluthrin (Force 3G)

- ★ Control=Fair
- ★ Mode of action permits use for resistance management
- ★ REI = 0 hours
- ★ Reliable performance in trials and field
- ★ Less toxic than some alternatives
- ★ Possible reduced rate use for insect control
- ★ Skin sensitivity

Permethrin (Pounce/Ambush)

- ★ Control=Fair to Good
- ★ Can be tank mixed with many herbicides
- ★ Has granular formulation
- ★ Can be applied through irrigation
- ★ Can cause mite flare
- ★ REI=12hours
- ★ PHI=30days

Lambda-cyhalothrin (Warrior)

- ★ Control=Excellent
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Excellent
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent

- ★ REI=24 hours
- ★ PHI=30 days

**Treatments to crop.**

Methyl Parathion (Penncap-M)

- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Fields need to be posted for Worker Protection Standards
- ★ REI= 48 hours
- ★ PHI=12 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Tillage applied at least two weeks before planting greatly reduces damage by this pest

**Adjust plant/harvest dates**

- ★ Not effective for this insect

**Pheromone traps**

- ★ Though not a control method, pheromone traps are used to indicate the presence or absence of insects and their relative prevalence. Pheromone traps are notoriously inconsistent and are often not reliable indicators of potential pest severity.

**Foliar feeding insects**

**4. Corn flea beetles** [*Chaetocnema pulicaria* Melsheimer]

- Corn flea beetles are small insects that feed on leaf surfaces where they abrade the surface tissue and cause minor loss of leaf photosynthetic material. Flea beetles play a major role in the transmission of Stewart's wilt, a bacterial disease of corn. The incidence of Stewart's wilt is generally tied to winter conditions that favor winter survival of corn flea beetles. The average air temperatures (in degrees F) for December, January and February are added and if the total is greater than 95, Stewart's wilt in susceptible popcorn lines is of special concern. If the 3-month sum of averages is below 95, the risk is relatively small.
- Scout and apply rescue treatments should corn flea beetle numbers reach the economic threshold
- Treatment is seldom used unless the popcorn hybrid has a known susceptibility to Stewart's disease.
- This pest is considered of minor importance in most areas of the eastern Corn Belt.

**Treatments to soil**

**Organophosphate**

Terbufos (Counter)

- ★ Control=Fair
- ★ Long life
- ★ Cost effective
- ★ Somewhat systemic
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control
- ★ Under cool, moist conditions and high pH may break down quickly
- ★ Use restrictions with some herbicides
- ★ Unpleasant to work with
- ★ Residue levels sometimes unpredictable
- ★ Concern of possible contamination of water supplies
- ★ REI= 48 hours or up to 72 hours in areas where average rainfall is less than 25 inches per year
- ★ Dry conditions tend to reduce control
- ★ More toxic (environmental and human) than other controls

Esfenvalerate (Asana)
- ★ Control=Good
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ REI=12 hours
- ★ PHI=21 days

**Carbamates**

Carbaryl (Sevin XLR)
- ★ Control=Good
- ★ Inexpensive
- ★ XLR formulation is long lasting
- ★ Low toxicity to humans
- ★ Treated fields need to be posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI=48 days

Carbofuran (Furadan)
- ★ Control=Good
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Permethrin (Pounce/Ambush) (Over the top)
- ★ Control=Good
- ★ Can be tank mixed with many herbicides
- ★ Can be applied through irrigation
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI=12 hours
- ★ PHI=30 days

Lambda-cyhalothrin (Warrior)
- ★ Control=Good
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)
- ★ Control=Good
- ★ Can be applied through irrigation
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Applications to Crop**

**Organophosates**

Methyl Parathion (Penncap-M)
- ★ Control=Fair
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation

- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transport to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Fields need to be posted for Worker Protection Standards
- ★ REI= 48 hours
- ★ PHI=12 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Not effective for this insect.

**Adjust plant/harvest dates**

- ★ Not effective for this insect.

**Pheromone traps**

- ★ Do not exist for this insect. (Not a control measure)

**5. Armyworm** [*Pseudaletia unipuncta* Haworth]

- Armyworm damage is characterized by ragged feeding and large amounts of frass (fecal pellets) on plants. The most severe damage occurs in popcorn fields that are no-tilled into grass or alfalfa sod. The grass is a favored oviposition site for adult moths that arrive from the gulf-coast states on strong southerly winds, similar to black cutworm. Often, the damage to young corn happens suddenly when the grass supply is consumed or when it is killed with a herbicide treatment. No-till fields must be observed closely, and treatments should be based on the presence of small armyworm larvae feeding on the grass.
- Very sporadic, but when it appears, it can be a significant pest - capable of destroying entire fields.
- Armyworms often move from wheat fields to popcorn fields as the season progresses.
- Scouting and spraying of field perimeter is an effective method of control -for example a no-till popcorn field near rye or other grassy field.
- This pest is considered of low to moderate importance to popcorn production.

**Treatments to standing crop**.

**Organophosphate**

Methyl Parathion (Penncap-M)

- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transport to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Fields need to be posted for Worker Protection Standards
- ★ REI= 48 hours
- ★ PHI=12 days

**Carbamates**

Carbofuran (Furadan)

- ★ Control=Good
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Permethrin (Pounce/Ambush)

★ Control=Good
★ Effective on lepidopterous insects
★ Can be tank mixed with many herbicides
★ Can be applied through irrigation
★ Liquid formulation needs fields posted for Worker Protection Standards
★ REI=12 hours
★ PHI=30 days

Esfenvalerate (Asana)

★ Control=Good
★ Effective on lepidopterous insects
★ Can be applied through irrigation
★ Some systemic activity
★ REI=12 hours
★ PHI=21 days

Lambda-cyhalothrin (Warrior)

★ Control=Good
★ Better efficacy and broader spectrum of control than most alternatives
★ Can be applied through irrigation
★ Has residual control
★ May kill beneficials
★ REI=24 hours
★ PHI=24 hours

Bifenthrin (Capture)

★ Control=Good
★ Can be applied through irrigation
★ Has long residual control
★ May kill beneficials
★ Not yet known whether performance is consistent
★ REI=24 hours
★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

★ Not effective for this insect

**Adjust Plant/harvest dates**

★ Not effective for this insect

**Pheromone traps**

★ Though not a control method, pheromone traps are used to indicate the presence or absence of insects and their relative prevalence. The quality of pheromone traps are notoriously inconsistent and are often not reliable indicators of potential pest severity.

**6. Stalk borer** [*Papaipema nebris* Guenee]

- Stalk borers are a native insect that damages popcorn by tunneling into plants and typically destroying the growing points. Damage is typically confined to field areas that are adjacent to borders of perennial grasses, including road ditches, terrace backslopes, and grassed waterways. Perennial grasses like quackgrass and wirestem muhly and large broadleaf weeds, especially hemp (*Cannabis sativa*) and giant ragweed (*Ambrosia trifida*) are favored oviposition sites in the fall, and if these weeds are disseminated throughout the field, general damage can occur. Typically, stalk borer damage is limited to border rows, and treatments can be targeted to those border areas.
- This pest has a moderate level of importance; there are few economic options, but local outbreaks can have a significant impact on yields.

**Treatments to Standing Crop**

**Organophosphate**

Methyl Parathion (Penncap-M)

★ Control=Good

- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transport to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI=12 days

**Carbamates**

Carbaryl (Sevin XLR)

- ★ Control=Good
- ★ Inexpensive
- ★ XLR formulation is long lasting
- ★ Low toxicity to humans
- ★ Treated fields need to be posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI=48 days

Carbofuran (Furadan)

- ★ Control= Fair
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Permethrin (Pounce/Ambush)

- ★ Control=Fair to Good
- ★ Can be tank mixed with many herbicides
- ★ Can be applied through irrigation
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI=12hrs
- ★ PHI=30d

Esfenvalerate (Asana)

- ★ Control=Good
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ REI=12 hours
- ★ PHI= 21 days

Lambda-cyhalothrin (Warrior)

- ★ Control=Fair to Good
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Fair to Good
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ Has residual soil activity

- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**
**Tillage (primary or cultivation)**
- ★ Clean tillage in the spring will destroy most overwintering eggs on weed residues in the field.

**Adjust plant/harvest dates**
- ★ Not effective for this insect

**Pheromone traps**
- ★ Not available for this insect. Not a control measure.

**7. European corn borer** [*Ostrinia nubilalis* Hubner]
- European Corn Borers (ECB) overwinter as larvae that pupate once the soil warms sufficiently in the spring. Moths emerge from these pupae in June, where the adults mate and females place eggs on the underside of corn leaves and on other suitable plant species. The moths prefer the tallest plants for oviposition, and when larvae hatch, they feed on leaf tissue. These larvae mature and pupate, with a second emergence of moths, usually occurring in late July and August.
- Second-generation ECB moths prefer late maturing corn for oviposition. The newly hatched second generation larvae feed lightly on leaves, but soon bore into leaf midribs, stalks and ear shanks. Economic thresholds for second generation corn borer are difficult to determine.
- This pest is of significant importance to popcorn production.
- Comparing yield and quality losses due to insect pressure, corn borer potentially causes more economic damage than corn rootworm. However, growers seldom treat infestations because the spray window for each generation is short, the cost of chemicals high, and multiple sprays are needed. The pest is also difficult to scout - especially second generation.
- Where rescue treatments are utilized, the product formulation is critical for effective control. When rescue treatment timing is accurate, granular products can give better control than liquid formulations. For rescue treatment of $2^{nd}$ generation - liquid products provide better control than granular formulations.
- In the eastern region of the Corn Belt, Kentucky tends to see more Bt usage towards corn borers than other states, and most of that is directed at the southwestern corn borer (See section below).

**Treatments to Standing Crop**
**Organophosphates**
Methyl Parathion (Penncap-M)
- ★ Control =Excellent
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field improves contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flare ups
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI=12 days

**Carbamates**
Carbaryl (Sevin XLR)
- ★ Control =Fair
- ★ Inexpensive
- ★ XLR formulation is long lasting
- ★ Low toxicity to humans
- ★ May flare mites and aphids

- ★ Treated fields need to be posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI=48 days

Carbofuran (Furadan)

- ★ Control=Good to Excellent
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control= Fair and variable
- ★ Effective on most lepidopterous insects except ECB
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ May cause mite flare ups
- ★ REI=12 hours
- ★ PHI= 21 days

Permethrin (Pounce/Ambush)

- ★ Control= Fair
- ★ Can be tank mixed with many herbicides
- ★ Has granular formulation
- ★ Can be applied through irrigation
- ★ Can cause mite flare ups
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI=12 hours
- ★ PHI=30 days

Lambda-cyhalothrin (Warrior)

- ★ Control=Good to excellent
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Good to excellent
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Synthetic-Organics**

Spinosad (Tracer)

- ★ Early introduction, unknown benefits/risks

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ No effect on this insect

**Adjust plant/harvest dates**

- ★ Early harvest of crop may be possible where ECB is present to preserve yields and quality

- ★ Cannot always delay planting as it may reduce yields or prevent planting altogether if late rains keep fields wet.

**Pheromone traps**

- ★ Though not a control method, pheromone traps are used to indicate the presence or absence of insects and their relative prevalence. Pheromone traps are notoriously inconsistent and are often not reliable indicators of potential pest severity.

**Pipeline Pest Management Tools:**

- ★ Nicotinoids - still in research phase

8. **Southwestern Corn Borer** (*Diatrea grandiosella* Dyar)

- In the southern portion of the Corn Belt; parts of Illinois, Indiana, Kansas, Kentucky, and Missouri, there is a complex of ECB and SouthWestern Corn Borer (SWCB). In these areas, economic losses attributed to SWCB is more frequent. In addition to the types of damage caused by ECB, second generation SWCB larvae increases harvest losses through plant lodging caused by girdling of the stalk 1 to 2 inches above the soil. While the biology of SWCB is similar to that of ECB, peak moth flights occur after those of ECB, causing extended periods of corn borer larval activity. Weather-related planting delays can cause serious exposure to harvest losses by late-season SWCB.

**For treatments see European Corn Borer above.**

9. **Corn rootworm** (western and northern) [Diabrotica sp.]

- The northern & western corn rootworm can infest from 40 to 50% of the popcorn grown in the region. The insect destroys the root system of the plant with up to 80% yield loss in some situations if left untreated.
- Adults lay eggs in late summer and early fall that hatch in early June of the following year. Corn RootWorm (CRW) larvae feed on a narrow range of host species. In general, a corn-soybean rotation disrupts their life cycle and constitutes the most effective management tool available for farmers.
- Some populations of northern CRW have shown a life cycle adaptation called extended diapause. Extended diapause occurs when some of the eggs rest through the next summer and hatch the second spring after being laid. With extended diapause, control by a popcorn-soybean rotation can fail. This is currently occurring in parts of Minnesota, Iowa, South Dakota, Illinois, (and to a lesser extent) Michigan and Ohio, and has resulted in a change in the dynamics of insecticide use in those areas.
- Recently, populations of western CRW have lost a preference to lay eggs in corn, and prefer to lay eggs in other non-corn crop fields, such as soybean. This phenomenon occurs in northern (near the Wisconsin border) and east-central Illinois, northern Indiana, northwestern Ohio, and in southern Michigan. With the western corn rootworm, soil-applied insecticide treatments are generally a standard practice in corn acreage following corn and non-corn crops that target the larvae.
- This pest is of significant importance to corn production.
- Because the chemicals have a finite ‘effective’ life in the soil, early planting tends to make chemicals less effective.
- Rootworm transgenic hybrids may become available in the near future, but are targeted to control only rootworms. As a result, they may not reduce the overall perceived risk of insect complexes and associated pesticide use.
- In the eastern portion of the Corn Belt, rootworm insecticides are applied in furrow or in bands. Allowing part of the field to remain untreated has relieved the resistance problems.

**Larval Stage Soil treatments**
**Organophosphate**

Terbufos (Counter) At planting application

- ★ Control=Good
- ★ Long life
- ★ Cost effective
- ★ Somewhat systemic
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control

- ★ Under cool, moist conditions and high pH may break down quickly
- ★ Use restrictions with some herbicides
- ★ Unpleasant to work with
- ★ Concern of possible contamination of water supplies
- ★ REI= 48 hours or up to 72 hours in areas where average rainfall is less than 25 inches per year
- ★ Dry conditions tend to reduce control
- ★ More toxic (environmental and human) than other controls

Chlorethoxyfos (Fortress)

- ★ Control = Good
- ★ 5G formulation applied with Smartbox reduces worker exposure
- ★ Smartbox pulsation causes erratic application of product
- ★ Consistency of performance of rootworm is low
- ★ REI=48 hours

**Organophosphate + Pyrethroid**

Tebupirimphos+cyfluthrin (Aztec)

- ★ Control=Good to Excellent
- ★ Good formulation
- ★ Good longevity
- ★ Smart Box reduces worker exposure
- ★ Possible reduced rate usage
- ★ REI=0 hours

**Carbamates**

Carbofuran (Furadan)

- ★ Control= Fair
- ★ Inconsistent performance
- ★ Liquid formulation only
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Tefluthrin (Force 3G)

- ★ Control = Good to Excellent
- ★ Mode of action permits use for resistance management
- ★ REI = 0 hours
- ★ Reliable performance in trials and field
- ★ Less toxic than some alternatives
- ★ Possible reduced rate use for insect control
- ★ Skin sensitivity

Bifenthrin (Capture)

- ★ Control= Fair to Good
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

**Pipeline Pest Management Tools:**

- ★ Nicotinoids - still in research phase

**Adjusting Planting/Harvesting dates**

- ★ Not effective for this insect.

**Treatments for adult beetles**

In the eastern Corn Belt, when thresholds for adults are reached; growers are encouraged to rotate crops in areas not impacted by the WCR that lays eggs in non-corn crop fields. Treatment for adult beetles primarily occurs in the western Corn Belt to prevent economic egg laying.

**Organophosphates**

Methyl Parathion (Penncap-M)

- ★ Control=Excellent
- ★ Long life
- ★ Encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field to guarantee contact with most pests
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flare ups
- ★ Fields need to be posted for Worker Protection Standards
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ CRW and other insect resistance in western Corn Belt
- ★ REI= 48 hours
- ★ PHI=12 days

**Carbamates**

Carbaryl (Sevin XLR)

- ★ Control=Excellent
- ★ Inexpensive
- ★ XLRR formulation is long lasting
- ★ Low toxicity to humans
- ★ May flare mites and aphids
- ★ Treated fields need to be posted for Worker Protection Standards
- ★ Adult resistance documented in western Corn Belt
- ★ REI= 12 hours
- ★ PHI= 48 days

Carbofuran (Furadan)

- ★ Control= Good
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control=Good
- ★ Effective on most lepidopterous insects except ECB
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ May cause flare up of mites
- ★ REI= 12 hours
- ★ PHI= 21 days

Permethrin (Pounce/Ambush) (Over the top)

- ★ Control=Good
- ★ Can be applied through irrigation
- ★ Can cause mite flare ups
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI=12 hours
- ★ PHI=30 days

Zeta-cypermethrin (Mustang)

- ★ Characteristics little known at time of writing

Lambda-cyhalothrin (Warrior)

- ★ Control=Good
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Good to Excellent
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Other non-chemical pest control measures**

**Tillage**

- ★ Not effective for Adult stage of this insect

**Adjusting Planting/Harvesting dates**

- ★ Not effective for this insect

**10. Corn leaf aphids** [*Rhophalosiphum maidis* Fitch]

- Corn leaf aphids are colonial sucking insects that can rapidly increase population numbers to cover the emerging tassels and youngest leaves of stage R1 popcorn plants. Although corn leaf aphid populations approaching 400 individuals per plant are necessary to warrant treatment, such populations do occasionally occur under favorable (dry) weather conditions. The primary damage from large populations is physiological, but secretion of honeydew can cause tassels to gum up and can reduce the effective dissemination of pollen. Scouting is most critical under drought conditions.
- Except under very dry conditions, this pest is of minor importance to popcorn production in most areas.
- Selection of insecticides may be driven by the availability of products.
- Treatment should occur soon after need is determined.

**Treatments to standing crop**.

**Organophosphate**

Methyl Parathion (Penncap-M)

- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flare ups
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI= 12 days

Dimethoate (Cygon)

- ★ Control=Good

- ★ Inexpensive
- ★ Somewhat systemic in plant (allows control of sucking insects)
- ★ Not readily available in Midwest
- ★ Short residual
- ★ Nauseating smell
- ★ REI= 48 hours
- ★ PHI= 14 days

**Carbamates**

Carbofuran (Furadan)

- ★ Control=Good
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control=Good
- ★ Effective on most lepidopterous insects except for ECB
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ May cause mite flare ups
- ★ REI= 12 hours
- ★ PHI= 21 days

Permethrin (Pounce/Ambush)

- ★ Control=Good
- ★ Can be tank mixed with many herbicides
- ★ Has granular formulation
- ★ Can be applied through irrigation
- ★ Can flare mites
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI= 30 days

Lambda-cyhalothrin (Warrior)

- ★ Control=Fair to Good
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Good
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ Has residual soil activity
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Not effective for this insect.

**Adjust plant/harvest dates**

- ★ Not effective for this insect.

**Pheromone traps**

- ★ Do not exist for this insect. (Not a control measure)

**11. Western bean cutworm** (*Richia albicosta* Smith).

- ★ This insect has been a pest of corn in Nebraska, Kansas, and Colorado and recently has moved into Iowa.
- ★ This insect causes severe kernel and ear damage. The resultant damage allows molds and mycotoxin development.
- ★ This pest frequently occurs on about half of all popcorn planted on sandy soils in the western region (averages about 15% acres infested overall in the west). Although worse on sandy soils, it also infests popcorn grown on other soils as well.

**Treatments to standing crop**.

**Organophosphate**

Methyl Parathion (Penncap-M)

- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flare ups
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI= 12 days

**Carbamates**

Carbofuran (Furadan)

- ★ Control=Good
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control=Good
- ★ Effective on most lepidopterous insects except ECB
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ May cause mite flare ups
- ★ REI=12 hours
- ★ PHI=21days

Permethrin (Pounce/Ambush)

- ★ Control=Good
- ★ Effective on lepidopterous insects
- ★ Can be tank mixed with many herbicides
- ★ Can be applied through irrigation
- ★ Can cause mite flare ups
- ★ Liquid formulation needs fields posted for Worker Protection Standards

- ★ REI=12 hours
- ★ PHI=30 days

Zeta-cypermethrin (Mustang)

- ★ Characteristics little known at time of writing

Lambda-cyhalothrin (Warrior)

- ★ Control=Excellent
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Excellent
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI= 24 hours
- ★ PHI= 30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Not effective for this insect

**Adjust Plant/harvest date**

- ★ Not effective for this insect

**Pheromone traps**

- ★ Not available for this insect (Not a control measure)

**12. Corn ear worm** (*Heliothis zea* Boddie)

- Two and sometimes three generations of corn ear worm are possible in the Midwest. The first generation larvae may burrow their way through the whorl leaving tell-tale holes in the leaves as they emerge from the whorl.
- Second generation corn ear worms emerge from eggs laid on or near the ear silk and migrate down into the ear where they burrow through kernels. The damage caused by CEW may increase the susceptibility of corn ears to the development of fungal diseases and toxins. Holes bored through the husk of ears reflect the exit of more mature larvae.

**Treatments to standing crop**.

**Organophosphate**

Methyl Parathion (Penncap-M)

- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transport to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flares
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI= 12 days

**Carbamates**

Carbofuran (Furadan)

- ★ Control=Good
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Pyrethroids**

Esfenvalerate (Asana)

- ★ Control=Good
- ★ Effective on most lepidopterous insects except for ECB
- ★ Can be applied through irrigation
- ★ Some systemic activity
- ★ May cause mite flare ups
- ★ REI= 12 hours
- ★ PHI= 21 days

Permethrin (Pounce/Ambush)

- ★ Control=Good
- ★ Effective on lepidopterous insects
- ★ Can be tank mixed with many herbicides
- ★ Can be applied through irrigation
- ★ Can flare mites
- ★ Liquid formulation needs fields posted for Worker Protection Standards
- ★ REI= 12 hours
- ★ PHI= 30 days

Lambda-cyhalothrin (Warrior)

- ★ Control=Excellent
- ★ Better efficacy and broader spectrum of control than most alternatives
- ★ Can be applied through irrigation
- ★ Has residual control
- ★ May kill beneficials
- ★ REI=24 hours
- ★ PHI=24 hours

Bifenthrin (Capture)

- ★ Control=Excellent
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ Not effective for this insect

**Adjust Plant/harvest date**

- ★ Not effective for this insect

**Pheromone traps**

- ★ Though not a control method, pheromone traps are used to indicate the presence or absence of this insect and its relative prevalence. The quality of pheromone traps are notoriously inconsistent and are often not reliable indicators of potential pest severity.

**13. Grasshopper** (predominantly 3 species: **differential** [*Melanoplus differentialis* Thomas], **two-striped** [*Melanoplus bivittatus* Say], **red-legged** [*Melanoplus femurrubrum* DeGeer])

- Grasshoppers are common mid- to late-summer pests of popcorn. These insects hatch in grassy field edges and other grassy areas where they will feed, and then gradually spread into production fields. The presence of grasshoppers in border areas is not necessarily a cause of alarm. Greatest yield losses are caused by the loss of leaf area during tassel and silking stages. A 20% loss of leaf area during this time will result in about 7% loss in yield. However, scouting is pertinent, because it is important to only treat when the population reaches economic thresholds. Adult grasshoppers are better controlled with some of the pyrethroid and carbamate insecticides.
- Cultural practice of delayed mowing of ditch banks, etc., will assist in keeping the grasshoppers out of production fields.
- Treating grassy or weedy borders, when grasshoppers are juveniles, will usually prevent the infestation of the whole field
- Grasshoppers are considered of low importance to popcorn production.

**Treatments to standing crop**.
**Organophosphate**
Methyl Parathion (Penncap-M)
- ★ Control=Good
- ★ Long life
- ★ Has encapsulated formulation
- ★ Can be applied through irrigation
- ★ Sufficient mobility in field may provide contact with most foliar insects
- ★ Extremely toxic to honey bees, encapsulation allows for compound to be transported to bee hives
- ★ Many commercial applicators will not apply (Too toxic)
- ★ Can cause mite flares
- ★ Fields need to be posted for Worker Protection Standards
- ★ CRW and other insect resistance
- ★ REI= 48 hours
- ★ PHI= 12 days

Dimethoate (Cygon)
- ★ Control=Good
- ★ Inexpensive
- ★ Somewhat systemic in plant (allows some control of sucking insects)
- ★ Not readily available in Midwest
- ★ Short residual
- ★ Nauseating smell
- ★ REI= 48 hours
- ★ PHI=14 days

**Carbamates**
Carbofuran (Furadan)
- ★ Good on grasshoppers
- ★ May cause mite flare ups
- ★ Inconsistent performance
- ★ Limited formulations
- ★ Fields need to be posted for Worker Protection Standards
- ★ Quite toxic -worker exposure concern
- ★ PHI= 30 days
- ★ REI= 14 days

**Non-chemical controls**
**Tillage (primary or cultivation)**
- ★ Not effective for this insect

**Adjust Plant/harvest date.**
- ★ Not effective for this insect

**Sanitation**
- ★ Trimming weeds and grasses around field borders during dry weather may encourage grasshoppers to move into the popcorn field

**Pheromone traps**

- ★ Not available for this insect. (Not a control measure)

**14. Spider mites** [*Tetranychus urticae* (Koch)] (**Two-spotted, Banks Grass**)

- Spider mites are not normally a serious pest of popcorn. They are controlled during most years by a naturally occurring disease. However, when there are prolonged periods of low humidity, the fungus is suppressed, allowing the spider mite population to proliferate. If adverse weather conditions continue, multiple treatments may be needed.
- In the eastern Corn Belt region mites are considered a minor pest of popcorn.

**Treatments to standing crop**.

**Organophosphate**

Propargite (Comite)

- ★ Control=Good (Better on two-spotted spider mite)
- ★ Must be applied before mites become a problem

Dimethoate (Cygon)

- ★ Control=Good (better on Banks grass spider mite)
- ★ Inexpensive
- ★ Somewhat systemic in plant (allows some control of sucking insects)
- ★ Not readily available in Midwest
- ★ Short residual
- ★ Nauseating smell
- ★ REI= 48 hours
- ★ PHI=14 days

**Pyrethroids**

Bifenthrin (Capture)

- ★ Control=Good to excellent
- ★ Can be applied through irrigation
- ★ Has long residual control
- ★ May kill beneficials
- ★ Not yet known whether performance is consistent
- ★ REI=24 hours
- ★ PHI=30 days

**Non-chemical controls**

**Tillage (primary or cultivation)**

- ★ No effect on this insect

**Adjust plant/harvest dates**

- ★ Planting early may help evade worst of infestation
- ★ Cannot always plant early as it may result in reduced yields

**Pheromone traps**

- ★ Not a control measure.

## Storage pests:

There are two basic storage issues. First, since the popping ability of popcorn is closely tied to a specific moisture content, post harvest storage of the grain is essential for adjusting moisture content prior to packaging and sale. As a result, popcorn storage is not considered optional. Second, because popcorn is for human consumption and has a higher value than field corn, it typically requires greater protection from stored insect pests, molds, and rodents, thus the ability to fumigate the storage bins is essential.

International shipping of popcorn offers challenges. An infestation that gets containerized and "heated up" in transit may find live infestations upon arrival. The process of solving this problem on the other side of the globe can be frustrating.

Major storage pests for popcorn:

**1. Flour Beetles, "Red"** *Tribolium castaneum* (Herbst) and **"Confused"** *Tribolium confusum*

These beetles are similar to the saw-toothed grain beetle in habits and types of products infested. It is a serious pest in flour mills and wherever cereal products and other dried foods are processed or stored. These flour beetles may impart a bad odor that affects the taste of infested products.

2. **Weevils " Rice",** *Sitophilus oryzae* (Linnaeus)**. "Granary",** *Sitophilus granarius* (Linnaeus)
   These weevils are similar in both appearance and habits. The name "Rice" is misleading, however, because it infests other grains besides rice. Adult rice weevils can fly and, in warm climates, can cause widespread damage to corn, wheat, and other grains before harvest. Although field infestations do not occur throughout the Midwest, post-harvest infestations do. Such infestations originate from shipped-in grain or from already infested storage. Adult Granary weevils cannot fly.

3. **Indian meal moth,** *Plodia interpunctella* (Hübner).
   Common to both stored grain and cereal products, Indian meal moth larvae cause damage in corn meal, packaged foods, bagged grain, and grain in storage. Attack is confined to surface layers of stored shelled corn and small grains. Larval feeding is characterized by a webbing of the material infested. The mature larvae then often leave the material and crawl about in search of a place to pupate.

**Empty bin treatments**
**Pyrethroids**
Cyfluthrin (Tempo SC)
- ★ Good residual control
- ★ Easy to use
- ★ Expensive
- ★ Skin sensitivity

**Organophosphates**
Malathion
- ★ Inexpensive
- ★ Poor efficacy on most insects for which it is applied

**Stored Grain Treatments**
**Organophosphates**
Pirimiphos-methyl (Actellic)
- ★ Control=Fair to Good for stored grain insects
- ★ Very open-ended label (has flexibility in applications)
- ★ Good crop/food safety
- ★ Smells bad
- ★ Expensive
- ★ The use of water to apply this product correctly is sometime detrimental in that it may result in secondary infections of fungus
- ★ Cannot reapply
- ★ Not acceptable in all countries
- ★ Skin sensitivity
- ★ Worker exposure concerns

**Fumigants**
Phosphine (Al, Mg)
- ★ Control=Good
- ★ Cost effective
- ★ About 90% of popcorn fumigated today is with phosphine (pre-packaged or pellets/tablets).
- ★ Alternative to methyl bromide
- ★ Can be used for import/export purposes
- ★ Very detailed application documentation (difficult to make sense of)
- ★ Low flash point
- ★ Reacts with water
- ★ Corrosive to soft metals

- ★ Requires air-tight structures
- ★ Requires specific training
- ★ Concern about worker exposure
- ★ Requires extended period of fumigation for good efficacy
- ★ Has residual dust and concern over disposal of packaging

Methyl bromide

- ★ Control=Good to excellent
- ★ Has shorter required fumigation period
- ★ Used for import/export purposes
- ★ About 10% is still fumigated with methyl bromide prior to packaging
- ★ Has residual control of pests
- ★ Reduces germination of seeds
- ★ Concern about worker exposure (colorless, odorless)
- ★ Registration loss by end of 2004

Sulfuryl floride

- ★ Control=Good
- ★ Other characteristics=unknown

**Other Pest Management Aids**

Controlled atmosphere (hot/cold air)

- ★ Control=Good
- ★ Can be very effective
- ★ Very safe
- ★ Useable in organic production
- ★ Need expensive capitalized equipment

BT (Dipel, etc)

- ★ Control =Good for Indian meal moth, not effective for beetles.
- ★ Safe to humans
- ★ Does not kill beneficials
- ★ Can be used in organic production schemes
- ★ Easy to apply in storage bins though can cause moisture migration
- ★ Suspected BT resistance in some insects
- ★ Breaks down in environment too quickly
- ★ Timing is very critical
- ★ Shelf life may be short if storage conditions are not ideal
- ★ Moisture needed for activation of granules

Diatomaceous Earth

- ★ Control=Fair to Good
- ★ Can be used for organic production
- ★ Relatively non-toxic
- ★ Creates residues on grain that are hard to remove
- ★ Deactivated by humidity
- ★ Hard to get uniform application
- ★ Abrasive to transfer equipment
- ★ Decreases air flow and product flow
- ★ Respiratory hazard
- ★ Dries skin and eyes

**Pipeline Products**

**Spinosad** (Tracer)

This is a relatively new product and very little is known of its strengths and weaknesses.

- ★ Level of control=Unknown

**Ecofume (2% phosphine and 98% carbon dioxide)**

- ★ A new product registered last year by the EPA. It is a methyl bromide alternative and a drop-in replacement for the popcorn industry. This product should be evaluated for use on stored popcorn.

**Pest Resistance**:

- ★ There is no known phosphine resistance at this time in North America. Malathion resistance by indian meal moth and red flour beetle is fixed in many regions of the US. Resistance can be overcome with phosphine by raising the dosage rate and doing a better job of sealing structures.

**Table 9. Crop Loss and the Percent of Area Infested by Insects** (Data provided by popcorn agronomists, 2001.)

| Common Name | Scientific Name | % Acres Infested at any level | yrs out of 10 pest treated | % Loss on infested area with current treatments | Avg loss % |
|---|---|---|---|---|---|
| Black Cutworm | *Agrotis ipsilon* | 2.00% | 2 | 3 | 0.01% |
| Corn Earworm | *Helicoverpa zea* | 1.00% | 1 | 1 | 0.00% |
| Western bean cutworm | *Richia albicosta* | 15.00%* | 5 | | 0.00% |
| Corn Rootworm, Northern& Western | *Diabrotica barberi Diabrotica virgifera virgifera* | 40.00% | 10 | 6 | 2.40% |
| Grubs (White & Japanese) | *Phyllophaga* spp | 20.00% | 10 | 5 | 1.00% |
| European Corn Borer | *Ostrinia nubilalis* | 40.00% | 6 | 18 | 4.32% |
| Japanese beetles | *Popillia japonica* | 35.00% | 1 | 2 | 0.07% |
| Other: Aphids, armyworms, wireworms, stalk borers | | 2.00% | 1 | 2 | 0.00% |
| Banks mite | *Oligonychus pratensis* | 1.00% | 1 | | 0.00% |
| Two-spotted mite | *Tetranychus urticae* | 4.00% | 1 | | 0.00% |
| Southwestern corn borer | *Diatraea grandiosella* | 3.00% | 1 | | 0.00% |
| **Stored Grain Insects** | | % bins infested | | | 0.00% |
| Indian Meal moth | *Plodia interpunctella* | 100.00% | 10 | 1 | 1.00% |
| Red Flour beetle | *Tribolium castaneum* | 100.00% | 10 | 1 | 1.00% |
| Confused Flour beetle | *Tribolium confusum* | 100.00% | 10 | 1 | 1.00% |
| All insects | | | | | 10.81% |

* Pest is problem in western States of Region only.

## Diseases:

Diseases are present to some extent every year and are responsible for reductions in both grain and seed quality. Losses from diseases vary from year to year and their occurrence is strongly influenced by weather conditions. While some diseases occur commonly they may not cause much damage, yet others have the potential to be very serious.

Methods of controlling plant diseases in popcorn characteristically fall into three categories. First, plant breeding efforts are the primary focus of improving plant resistance and tolerance to the chronic effects of plant disease wherever possible. Second, tillage and crop management options are utilized to minimize the impact of the disease. Third, the use of fungicides, both as seed treatments and as foliar applications, are used where necessary to prevent crop losses where breeding and cultural management techniques fall short.

Historically, plant breeding and crop management techniques have minimized the impact of many existing diseases. It is possible, however, that a new disease, new viral race, or a new biotype of an existing disease will negate much of the impact of plant breeding and crop management. It is for this reason that new fungicides and disease management techniques continue to be developed and available for use.

Although there are a number of tillage and management practices listed below that may reduce the severity of a pest on popcorn, it should be remembered that these also may have impacts on production. Late planting, while minimizing some diseases, usually makes insect control more of a challenge for popcorn growers. On the other hand, early harvest, while reducing the frequency of some stalk and ear diseases, may lower grain quality much more than would a similar practice for field corn. For example, harvesting popcorn at a moisture level of greater than 18% severely reduces kernel popability. The utility of each practice must be weighed against possible disadvantage.

Not all diseases are economical to treat. The use or non-use of a fungicide is highly dependent on the economics of corn production, the perceived losses caused by the disease, and the cost of the treatment. Many foliar diseases, once evident in the field, are difficult or impossible to treat effectively. As a result, popcorn is seldom treated with foliar sprays. Seed decay and seedling blights, however, are almost always treated with fungicidal seed treatments. Seed treatments are highly effective against these diseases and are very economical to use.

While it is generally accepted that the focus on high yields in breeding programs has resulted in popcorn plants with greater overall disease tolerance, grower observations suggest that some of the newest hybrids may have greater susceptibility to plant diseases. It's important to note that yield is not the most important trait in popcorn improvement. Though yield is important, popping expansion traits are more critical to processors. It is unclear at this time how plant populations, crop rotations, and other management practices may be contributory factors to quality traits. However, if these observations prove to be true, there may be a greater need for foliar fungicide treatments in the foreseeable future.

Though a number of fungicidal products and classes are available for plant diseases in popcorn, it is deemed essential that this wide selection of products continue to be available to producers to provide the tools necessary for resistance management programs. As new diseases become evident and as existing diseases adapt to current cultural and chemical controls, it is important to have on hand effective and economical treatments. Though most diseases are sporadic in their occurrence and level of importance, without effective fungicides they can cause devastating losses for individual producers.

Throughout the discussion below comments are made regarding the relative susceptibility of sweet corn, field corn, or other corn types to popcorn diseases. This information is provided because these corn types are prevalent throughout the Corn Belt and they may be a source of inoculum for popcorn diseases. Though popcorn grown for seed is not covered specifically in this document, inbred seed corn lines also vary in susceptibility to the plant diseases listed below. Due to its higher value we can assume that more seed popcorn is treated for diseases than is standard popcorn.

Within the discussion of plant diseases below can be found a number of references to increased disease severity where the soils are cool, damp, and covered with residue. Almost without exception, fields that are poorly drained, planted early in the season, or managed with reduced till, have a higher incidence of plant diseases. Though each of these factors can be controlled by the grower in some degree, it is the latter factor, reduced tillage, that presents a dilemma for many growers as they try to reduce erosion and raise a healthy crop. For these growers, having effective fungicides for disease control remains a very high priority.

For discussion purposes, plant diseases are grouped below into broad categories. These categories include: Seed Decay and Seedling Blights, Root Rots, Foliar and above ground diseases, Ear and Kernel Rots, and Nematodes.

Crop diseases are present every year to some degree, however, the severity varies greatly depending on weather and field factors such as tillage, drainage, and sources of inoculum. The following plant diseases are those most commonly found on popcorn in the North Central States.

**1. Seed Decay and Seedling Blight**

- These diseases are generally caused by soil-inhabiting fungi such as *Pythium, Fusarium, Diplodia, Rhizoctonia,* and *Penicillium*. These fungi also may be seedborne, except for *Pythium*. Seeds may be rotted before germination or the seed may germinate and the seedling infected and blighted (damping-off). This can occur as either pre-emergence damping-off or post-emergence damping-off.
- Damping-off is favored by cool, wet soils, so it is more common in low-lying or poorly drained areas or in fields planted too early in the spring.
- Heavy residue on the soil surface can favor damping-off by suppressing soil temperature and drying.
- Other factors that delay germination and emergence such as herbicide damage, compaction, crusting, or planting too deep, can result in more seedling blight.
- Controlled by seed treatment only.
- Human exposure once the seed is in the ground is minimal and would only occur when loading seed into planter and checking planter boxes or moving seed. Seed comes already treated in bag.
- Very little popcorn replanted due to seedling blight because of treated seed.
- Seed treatment lasts just long enough to get seed germinated.

**Chemical controls:**
**Phenylpyroles**
Fludioxonil (Maxim)

★ Control=Excellent
★ Seed applied
★ Low dust
★ Easy to apply
★ Generally reliable
★ REI= none
★ PHI= none

**Phenylthalimides**
Captan (Captan)

★ Control =Good
★ Seed applied by company
★ Older product- industry standard for years-reliable
★ Is combined with Maxim and other seed treatments
★ REI=none
★ PHI=none
★ Dusty (worker exposure concern)

**Phenylamides**
Metalaxyl (Apron)

★ Control =Excellent
★ Seed applied
★ Broad spectrum and generally reliable
★ More expensive than alternatives
★ Especially good in cool, wet soils
★ REI=none
★ PHI=none

**Ethylenebisdithiocarbamates**

★ Concern over worker exposure to EBDCs

Mancozeb (Dithane, Mancozeb, etc) (also penncozeb)

★ Control=Good
★ Inexpensive
★ Readily available

- ★ REI=24 hours
- ★ PHI=77 days
- ★ Timing critical

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

- ★ None

**Tillage and Field Sanitation effects**

- ★ Not effective/available for this pest

**Adjust Plant/harvest dates**

- ★ Delaying planting for warmer/dry soils can help with many soil borne diseases, however, it is necessary to 'outguess' the weather as later plantings may encounter heavy rain as well and may increase exposure to other insect and fungal pests
- ★ For damping-off plant corn when the soil temperature is above 50˚F and soil moisture is not excessive
- ★ Delaying planting may result in increased grain moisture content at harvest, reducing grain quality

**Crop rotation effects**

- ★ Inexpensive but of marginal efficacy
- ★ Not practical in many situations and can be expensive depending on government programs

**Resistant Hybrids**

- ★ Not effective for this disease

**2. Root Rots**

- Root rots of popcorn are very common, and can be caused by a number of fungal pathogens including *Pythium graminicola, Fusarium graminearum* and other *Fusarium* species, and *Exserohilum pedicellatum*. Losses to root rots vary substantially from year to year, and are difficult to estimate. Root rots occur to some extent in every field. But under wet conditions, root rots cause economic losses.
- Wet soil conditions predispose plants to root rots because of oxygen deficiency, and the root rot fungi thrive under these conditions.
- Highly compacted or otherwise poorly drained soils are particularly prone to root rots. Many of the stalk rot pathogens enter through the roots and cause a root rot in advance of the stalk rot.
- Root rots are generally not economically significant under good growing conditions and are considered of minor importance to popcorn production.
- Root rots are primarily controlled by resistant varieties.

**Chemical controls:**

- ★ None available, however, the seed treatments used for seedling rots and seed decay have some effect on root rots

**Pipeline pest management tools:**

- ★ None available

**Other pest management aids:**

**Tillage and Field Sanitation effects**

- ★ Improved drainage reduces the risk of root rots when wet conditions occur. Soil drying can be enhanced through a reduction in surface residue or cultivation, but the value of these practices in reducing root rot has not been demonstrated.

**Adjust Plant/harvest dates**

- ★ Delaying planting for warmer/dry soils can help with many soil borne diseases, however, it is necessary to 'outguess' the weather as later plantings may encounter heavy rain as well and may increase exposure to other insect and fungal pests
- ★ Delaying planting may result in increased grain moisture content at harvest, reducing grain quality

**Crop rotation effects**

- ★ Control for root rots is fair (at best)
- ★ Inexpensive
- ★ Not practical in many situations and can be expensive depending on government programs

**Resistant Hybrids**

- ★ Most hybrids are tolerant to some degree of root rot. Some hybrids are more resistant than others, but high levels of root rot resistance are not available.

**Foliage and Aboveground Diseases**

**3. Eyespot**

- Eyespot is caused by the fungus *Aureobasidium zeae*, previously known as *Kabatiella zeae*. This fungus overwinters in corn residue and in wet conditions produces conidia that are spread by splashing water and wind. The disease is much more common when popcorn follows other corn. Eyespot may appear early in the season on lower leaves and again near the end of the season on upper leaves.
- Eyespot is more prevalent in the northern part of the Corn Belt.
- Early maturing hybrids seem to be more susceptible.
- Field corn is seldom treated with foliar fungicides for this disease but popcorn can be treated on occasion.

**Chemical controls:**

**Triazoles**

Propiconazole (Tilt)

- ★ Control=Good
- ★ Easy to use
- ★ Reliable
- ★ REI=24 hours
- ★ PHI=0 days
- ★ Narrow application window
- ★ Timing critical
- ★ Expensive
- ★ No post silking use

Azoxystrobin (Quadris)

- ★ Control=Good
- ★ Broad spectrum
- ★ Longer residual than propiconazole
- ★ Easy to use
- ★ REI= 4 hours
- ★ PHI= 7 days
- ★ Maximum of 2 applications per season
- ★ Expensive

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and Field Sanitation effects**

- ★ Control=Good
- ★ Expensive
- ★ Soil erosion

**Adjust Plant/harvest dates**

- ★ Not effective for this pest

**Crop rotation effects**

- ★ Control=Good
- ★ Not practical in many situations and can be expensive depending on government programs

**Resistant Hybrids**

- ★ Control=Good

**4. Common smut**

- Common smut is caused by the fungus *Ustilago zeae*, previously known as *Ustilago maydis*, which overwinters in corn residue or soil. This fungus produces black teliospores that survive well in soil. These teliospores germinate during the spring and summer, with each teliospore then producing four smaller spores, called sporidia. These are spread by wind and water. All above ground plant parts are susceptible, especially the actively growing meristematic tissue.

Sporidia can infect through unwounded cells, but wounds caused by insects, detasseling, cultivation, hail, or blowing soil are important infection sites as well.

- Disease is favored by excess nitrogen, excess manure or herbicide injury, and relatively dry, warm weather.
- This disease is of low importance to popcorn production.
- Smut is not a health issue to humans or livestock.

**Chemical controls:**

★ None

**Pipeline pest management tools:**

★ None

**Other pest management aids:**

**Tillage and Field Sanitation effects**

★ Not effective for this disease

**Adjust Plant/harvest dates**

★ Not effective for this disease

**Crop rotation effects**

★ Not effective for this disease

**Resistant hybrids**

★ Control =Good

**5. Head Smut**

- Aggravated by crop injury from hail, cultivators, etc. Control can be affected by avoiding mechanical injury and establishing well-balanced soil fertility.

*See Common Smut above for additional control information.*

**6. Northern Corn Leaf Blight**

- Northern leaf blight is caused by the fungus *Exserohilum turcicum*, previously called *Helminthosporium turcicum*. The fungus overwinters as mycelium and spores in corn residue. Spores are dispersed by wind and splashing water. There are at least four races of the fungus.
- This has traditionally been the most consistently damaging leaf disease of field corn in the northern Corn Belt, but its severity has decreased due to improvements in resistance. It occurs throughout the eastern half of the United States, as far west as eastern Nebraska.
- Disease development is favored by extended periods of leaf wetness (rain or dew) and moderate temperatures (64-81˚F).
- This disease is important to corn production but rarely treated.

**Chemical controls:**

**Triazoles**

Propiconazole (Tilt)

★ Control=Good
★ Easy to use
★ Reliable
★ REI= 24 hours
★ PHI= 0 days
★ Narrow application window
★ Timing critical
★ Expensive
★ No post silking use

Azoxystrobin (Quadris)

★ Control=Good to Excellent
★ Broad spectrum
★ Longer residual than propiconazole
★ Easy to use
★ REI= 4 hours
★ PHI= 7 days

★ Expensive

**Substituted Benzenes**

Chlorothalonil (Bravo)

★ Control= Fair
★ Inexpensive
★ Readily available
★ Seldom has food residue above tolerance
★ REI= 48 hours
★ PHI= 14 days
★ Marginal efficacy on most diseases

**Pipeline pest management tools:**

None

**Other pest management aids:**

**Tillage and field sanitation effects**

★ Control=Good
★ Less chemical dependency
★ Expensive
★ Soil erosion

**Adjust Plant/harvest dates**

★ Not effective for this disease

**Resistant Hybrids**

★ Control=Good to Excellent

**7. Helminthosporium leaf spot**

- Helminthosporium leaf spot or northern leaf spot is caused by the fungus *Bipolaris zeicola*, previously known as *Helminthosporium carbonum*. There are five known races of this fungus with different virulence characteristics and symptoms. Race 0 is nearly avirulent to corn, and race 1 is virulent on only a few genotypes. Races 2 and 3 are the most common races in the Midwest. Race 2 is not specific for corn genotypes, while race 3 is only a problem on certain susceptible lines. A fifth race has been reported recently.
- *B. zeicola* overwinters as mycelium and spores in corn residue, and the spores are dispersed by wind and splashing water. It is favored by high humidity and moderate temperatures.
- This disease rarely occurs in modern hybrids and is not treated with fungicides.

**Chemical controls:**

**Triazoles**

Propiconazole, (Tilt)

★ Control=Good
★ Easy to use
★ Reliable
★ REI=24 hours
★ PHI=0 days
★ Narrow application window
★ Timing critical
★ Expensive
★ No post silking use

Azoxystrobin (Quadris)

★ Control=Good to excellent
★ Broad spectrum
★ Longer residual than propiconazole
★ Easy to use
★ REI= 4 hours
★ PHI= 7 days
★ Expensive

**Substituted Benzenes**

chlorothalonil (Bravo)

★ Control= Fair

- ★ Inexpensive
- ★ Readily available
- ★ Seldom has food residue above tolerance
- ★ REI= 48 hours
- ★ PHI= 14 days
- ★ Marginal efficacy on most diseases

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Control=Good
- ★ Less chemical dependency
- ★ Expensive
- ★ Soil erosion

**Adjust Plant/harvest dates**

- ★ Not effective for this disease

**Crop rotation effects**

- ★ Control=Good
- ★ Inexpensive
- ★ Not practical in many situations and can be expensive depending on government programs

**8. Anthracnose leaf blight**

- Anthracnose leaf blight is caused by the fungus *Colletotrichum graminicola*, the same fungus that causes anthracnose stalk rot. It overwinters as mycelium or sclerotia in corn residue or seed. Several weed species are also hosts and may act as inoculum sources.
- Spores are spread primarily by splashing water.
- Disease development is favored by wet weather with moderately warm temperatures. Anthracnose is much more common where corn follows corn.
- Anthracnose is usually more severe in the eastern corn states, but its importance in the Midwestern states is increasing.
- This disease occurred in outbreak proportions in 2000, but was not much of a problem in 2001. Problems are usually localized but can be severe.
- There is a noticeable trend for greater occurence in recent years.
- Anthracnose is not economical to treat for; normally too late to treat once symptoms are seen.

**Chemical controls:**

**Triazoles**

Propiconazole (Tilt)

- ★ Control=Good
- ★ Easy to use
- ★ Reliable
- ★ REI=24 hours
- ★ PHI=0 days
- ★ Narrow application window
- ★ Timing critical
- ★ Expensive
- ★ No post silking use

Azoxystrobin (Quadris)

- ★ Control=Good to excellent
- ★ Broad spectrum
- ★ Longer residual than propiconazole
- ★ Easy to use
- ★ REI= 4 hours
- ★ PHI= 7 days
- ★ Expensive

**Substituted Benzenes**

Chlorothalonil (Bravo)

- ★ Control=Fair
- ★ Inexpensive
- ★ Readily available
- ★ Seldom has food residue above tolerance
- ★ REI= 48 hours
- ★ PHI= 14 days
- ★ Marginal efficacy on most diseases

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Control=Good
- ★ Less chemical dependency
- ★ Expensive
- ★ Soil erosion

**Adjust Plant/harvest dates**

- ★ Not effective for this disease

**Crop rotation effects**

- ★ Control=Good
- ★ Inexpensive
- ★ Not practical in many situations and can be expensive depending on government programs
- ★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures.

**Resistant Hybrids**

- ★ Resistant hybrids are available, but resistance to anthracnose leaf blight and anthracnose stalk rot are not necessarily found in the same hybrid.

**9. Gray leaf spot**

- Gray leaf spot is caused by the fungus *Cercospora zeae-maydis*. The fungus survives as mycelium in corn residue, and spores are dispersed by wind and splashing water.
- This disease is a problem in the eastern United States, and it has grown in importance in the western Corn Belt as far west as central Nebraska. Gray leaf spot is much more common in the southern half of the North Central Region. It is particularly severe when corn follows corn. In Michigan it is found predominantly where irrigation is used.
- Sporulation and disease development are favored by warm, humid weather.
- This is a widespread and economically significant problem in corn production.
- Some varieties have tolerance.

**Chemical controls:**

**Triazoles**

Propiconazole (Tilt)

- ★ Control=Good
- ★ Easy to use
- ★ Reliable
- ★ REI=24 hours
- ★ PHI=0 days
- ★ Narrow appl window
- ★ Timing critical
- ★ Expensive
- ★ No post silking use

Azoxystrobin (Quadris)

- ★ Control=Good
- ★ Broad spectrum
- ★ Longer residual than propiconazole
- ★ Easy to use
- ★ REI= 4 hours
- ★ PHI= 7 days

- ★ Expensive

**Substituted Benzenes**

Chlorothalonil, (Bravo)

- ★ Control=Fair
- ★ Inexpensive
- ★ Readily available
- ★ Seldom has food residue above tolerance
- ★ REI= 48 hours
- ★ PHI= 14 days
- ★ Marginal efficacy on most diseases

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Control=Good
- ★ Less chemical dependency
- ★ Expensive
- ★ Soil erosion

**Adjust Plant/harvest dates**

- ★ Not effective for this disease

**Crop rotation effects**

- ★ Control=Good
- ★ Inexpensive
- ★ Not practical in many situations and can be expensive depending on government programs
- ★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures

**Resistant Hybrids**

- ★ Some hybrids are more tolerant to gray leaf spot, but control is variable and may not be adequate

**10. Stewart's Disease**

- This disease, also called Stewart's wilt or bacterial wilt, is caused by the bacterium *Erwinia stewartii*, which overwinters in the gut of the corn flea beetle (*Chaetocnema pulicaria*). The occurrence of this disease is strongly linked to the winter survival rate of the corn flea beetle, because the beetle introduces the pathogen into the corn plants as it feeds and carries the bacterium from plant to plant. The beetles survive in high numbers following a mild winter, resulting in high disease levels. If the sum of the mean monthly temperatures for December, January and February is 90˚F or more, the beetles will survive and the threat of Stewart's wilt is high. The disease can be spread by insects other than the flea beetle, but they are not as important. Stewart's disease is also seedborne, but seed transmission is very rare.
- This disease is more common in the southern and eastern parts of the Corn Belt.
- Dent corn is not very susceptible except for a few inbreds, but sweet corn can be very susceptible.
- This disease is of increasing importance in recent years. Perhaps because more flea beetles are able to overwinter due to mild temperatures and a greater number of winter annual weeds.
- Monitoring for flea beetles is important.
- Winter annual weed control greatly reduces concerns with beetles.
- This disease is considered of low to moderate importance to popcorn production but economical losses are possible if severe (insect) problem not treated. This disease has a lower economic threshold than other diseases. Therefore, scouting for flea beetle after corn emergence is very important.
- Stewart’s wilt can be managed to a great degree with hybrid selection.
- Aggravated by dry weather and temperatures above 30F average for Dec., Jan., and Feb. (This is when beetles, which vector the disease, migrate).

**Chemical Controls:**

- ★ Control of disease consists of controlling flea beetles; no cost effective treatments for disease

**Pipeline pest management tools:**

★ Cruiser Insecticide This is a systemic insecticide that may significantly help reduce problems with leaf aphids and flea beetles, thus reducing the incidence of Stewart's wilt. It will be seed applied, and therefore convenient to use and apply.

**Other pest management aids:**

**Resistant varieties**

★ Principal method of control

★ Most hybrids are resistant enough that no further management is required.

**Tillage and field sanitation effects**

★ Control= Poor

★ Less chemical dependency

★ Expensive

★ Soil erosion

★ Most cultural practices do not influence Stewart's disease because the pathogen survives in the flea beetle. Weed control may have some effect because the insects prefer grassy weeds and damage to popcorn is highest in weedy fields.

**Adjust Plant/harvest dates**

★ Not effective for this disease/insect

**Crop rotation effects**

★ Not effective for this disease/insect

**Pipeline pest management tools:**

★ None

**11. Stalk Rots**

- Stalk rots are a consistent problem in corn production, causing yield losses through premature plant death and/or lodging. When plants die prematurely, the result is poor yields and low test weight grain. If a plant with severe stalk rot survives to maturity, yield may not be greatly affected. However, rotted stalks will easily lodge, making harvest impossible. Stalk rots are caused by several different fungi that infect plants through the roots or through wounds in the stalk. The major stalk rot pathogens are *Gibberella zeae*, Fusarium species, and *Colletotrichum graminicola* (anthracnose), and most recently, *Diplodia maydis.*
- The occurrence of stalk rots is strongly affected by stresses on the corn plant during the grain filling stage of development. Any conditions that reduce photosynthesis and the production of sugars can predispose the plant to severe stalk rot. Such stresses include high plant populations, severe leaf diseases or hail damage, drought or soil saturation, lack of sunlight, extended cool weather, low potassium in relation to nitrogen, and insect damage. Insects such as the European corn borer cause stress to the plant as well as providing wounds for entrance of the stalk rot fungi. Many stalk rot infections can be traced back to stalk boring insect wounds. Early maturing hybrids sometimes suffer more stalk rot damage than full-season hybrids.
- Stalk rots are a sporadic and seasonal problem and are considered of minor importance in popcorn production.

**Chemical controls:**

★ None

**Pipeline pest management tools:**

★ None

**Other pest management aids:**

★ Severe stalk rot can be avoided by reducing the stresses that predispose plants. This means balanced fertilization, appropriate plant population and adapted hybrids, insect and weed control, avoidance of root and stalk injury, good drainage, proper irrigation (where applicable), and using hybrids that are resistant to foliar diseases.

**Tillage and field sanitation effects**

★ Very little effect on disease

★ Less chemical dependency

★ Expensive

★ Soil erosion

**Adjust Plant/harvest dates**

- ★ Control=Fair (At best)
- ★ Delaying planting for warmer/dry soils can help with many soil borne diseases, however, it is necessary to 'outguess' the weather as later plantings may encounter heavy rain as well and may increase exposure to other insect and fungal pests
- ★ Delaying planting may result in increased grain moisture content at harvest, reducing grain quality
- ★ In general, losses to stalk rots can be reduced by scouting fields 40 to 60 days after pollination and looking for symptoms or pinching stalks. If more than 10 to 15 percent of stalks are rotted, the field should be scheduled for the earliest possible harvest.

**Crop rotation effects**

- ★ Control=Fair (at best)
- ★ Inexpensive
- ★ Not practical in many situations and can be expensive depending on government programs

**Resistant Hybrids**

- ★ Resistance is available for some stalk rots, and some hybrids are tolerant of stalk rots (will not lodge even if rotted)

**12. Ear and Kernel Rots**

**12a. Fusarium Rots**

Fusarium ear and kernel rot is the most common ear disease in the Midwest. It is caused by several fungi in the genus *Fusarium*, but *F. moniliforme* is considered to be the primary species on corn in the Midwest. Fusarium ear rot occurs under a wide range of weather conditions. The fungus causes a stalk rot and can colonize any part of the corn plant, overwintering in the corn residue and on dead grassy weeds. *F. moniliforme* also is commonly found in corn seed. *Fusarium* spores are spread by wind and splashing rain to the silks, which are most susceptible for the first 5 days after they appear. Infections also occur through wounds made by insects or other types of wounds in the kernels. There is some evidence that insects act as vectors of *Fusarium*. *F. moniliforme* can grow throughout the corn plant, and some ear infections may be the result of the fungus entering the ear through the shank. Several of the *Fusarium* species causing corn ear rot can produce harmful mycotoxins, so caution should be used in feeding molded corn. *Fusarium* species usually do their damage in the field, but they can be a problem in storage if grain moisture is 18 percent or above.

**12b. Gibberella ear rot**

This ear rot is common throughout the Midwest. It is caused by the fungus *Gibberella zeae* which is the sexual reproductive stage of *Fusarium graminearum*. This fungus also causes a stalk rot, and overwinters in corn residue. The spores are spread by splashing rain and wind infecting ears through the silks. Silks are most susceptible 2 to 6 days after emergence. The disease is favored by cool, wet weather after silking. This is the most consistently important mycotoxigenic fungus in the northern Corn Belt, producing vomitoxin, zearalenone, and other toxins. *Fusarium* species usually do their damage in the field, but they can be a problem in storage if grain moisture is 18 percent or above.

**12c. Diplodia ear rot**

Diplodia ear rot is caused by the fungus *Diplodia maydis* (Stenocarpella maydis), which also causes Diplodia stalk rot. This disease is not typically as common as Fusarium or Gibberella ear rots, but it can be destructive when it occurs. The fungus overwinters as mycelium, spores, and pycnidia on corn residue or seed. The spores are spread primarily by splashing rain. The infection process for this disease is poorly understood, but infections first appear at the base of the ear. Corn borer damage in the shank can provide an entry wound for the pathogen. Diplodia rot is favored by cool, wet weather during grain fill. Rainfall during August, September, and October is correlated with Diplodia ear rot incidence. *D. maydis* is not known to produce harmful mycotoxins. *Diplodia maydis* usually does its damage in the field, but it can be a problem m storage if grain moisture is 20 percent or above.

**Control of ear and kernel rots**

- ★ Control of the various ear and kernels rots can be achieved by similar practices. Prevention of their occurrence is difficult because of their dependence on weather and the limited affects of cultural practices. Control of these diseases places an emphasis on harvest and grain handling.
- ★ These diseases have a high importance to corn production as the toxins produced by molds can be a serious health issue for humans and livestock.

- ★ Diplodia is known to be more severe in some specialty corn types such as high oil corn.
- ★ Concern over these diseases could rapidly escalate if FDA sets levels for mycotoxins at unachievable levels.

**Chemical controls:**
**Pipeline pest management tools:**
- ★ None

**Other pest management aids:**
**Tillage and field sanitation effects**
- ★ Control=Fair (at best)
- ★ Less chemical dependency
- ★ Expensive
- ★ Soil erosion

**Adjust Plant/harvest dates**
- ★ Not effective for this disease

**Crop rotation effects**
- ★ Crop rotation can reduce the occurrence of some ear rots, such as Diplodia. Others may not be affected much because of the movement of spores from neighboring fields.

**Resistant Hybrids**
- ★ Tolerance to the ear rots varies among hybrids, although complete resistance is not available. Hybrids with tight husk coverage and ears that do not remain erect after maturity tend to suffer less damage. (Keep moisture out of ear)

**Other**
- ★ Control of insect and wildlife feeding may reduce ear rots to some extent.
- ★ Scout fields as the corn begins to dent and identify areas with mold problems. Harvest these areas as soon as possible to prevent further mold development.
- ★ Properly adjusted combines will reduce kernel damage. Damaged kernels are more susceptible to mold development. Combine adjustments also can be used to help discard light weight, moldy kernels during combining.
- ★ Cleaning grain before drying will remove the fine particles that are often the moldiest and most toxic component of grain.
- ★ Moldy grain should be dried immediately and rapidly to 15 percent or less (13-14 percent for long-term storage). Holding this grain for even a short time can result in substantial mold and toxin development. Grain that does not have obvious mold problems also should be dried immediately, but there may be more economical options to rapid, high-temperature drying.
- ★ Cool the grain after drying.
- ★ Clean bins before storing new grain.
- ★ Aerate and stir stored grain; periodically check for condensation and mold growth.
- ★ Control storage insects.
- ★ Antifungal agents such as propionic acid can retard mold growth in storage, but they do not kill fungi already present or destroy toxins that are already formed
- ★ Test molded grain for mycotoxins prior to feeding.
- ★ Dry and market corn immediately. Don't store it.

**13. Common Rust**
- ★ This disease is aggravated by: cool temps (65-75 F), light rains, heavy dews, and high humidity. It is spread when the urediniospores are windblown from previously infected leaves. Losses range from 0-50% (depending on environment and resistance) Control includes: resistant varieties and foliar fungicides.
- ★ Some hybrid tolerance
- ★ Very common disease but not economical to treat in most cases. Tilt and Quadris are available for rust control but are usually too expensive to use.

**Chemical controls:**
**Phenylpyroles**
**Triazoles**
Propiconazole (Tilt)

- ★ Control=Fair to Good
- ★ Easy to use
- ★ Reliable
- ★ REI=24 hours
- ★ PHI=0 days
- ★ Narrow application window
- ★ Timing critical
- ★ Expensive
- ★ No post silking use

Azoxystrobin (Quadris)

- ★ Control=Good to excellent
- ★ Broad spectrum
- ★ Longer residual than propiconazole
- ★ Easy to use
- ★ REI= 4 hours
- ★ PHI= 7 days
- ★ Expensive

**Substituted Benzenes**

Chlorothalonil (Bravo)

- ★ Control=Fair
- ★ Inexpensive
- ★ Readily available
- ★ Seldom has food residue above tolerance
- ★ REI= 48 hours
- ★ PHI= 14 hours
- ★ Marginal efficacy on most diseases

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Not effective for this disease

**Adjust Plant/harvest dates**

- ★ Not effective for this disease

**Crop rotation effects**

- ★ Not effective for this disease

**Resistant Hybrids**

- ★ Some hybrids have resistance to common rust but tolerance if variable

**14. Goss's Wilt**

**Chemical Control**

- ★ None

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Not effective for this disease

**Adjust Plant/harvest dates**

- ★ Not effective for this disease

**Crop rotation effects**

- ★ Control=Good

**Resistant Hybrids**

- ★ Control=Good

**15. Maize Dwarf Mosaic Virus**

- This disease is spread by insect vectors.

- Early infections may expose popcorn to root and stalk rots causing premature death. Symptoms can appear in the field within 30 days after seedling emerge.
- Control includes: resistant hybrids and control of rhizome Johnsongrass or other overwintering weed hosts.

*For control of viruses see Insect Control section above.*

**16. Nematodes**

- Every field contains nematodes actively feeding on plants. Nematodes that attack popcorn are microscopic roundworms, approximately 3/10 to 3/64 inch long. The presence of nematodes depends on the soil type and its properties, other soil microorganisms, cropping history, climatic factors such as temperature and rainfall, tillage practices, and the use of pesticides. Nematodes can feed without causing appreciable yield loss if nematode numbers are low and/or the environmental conditions are such that the popcorn crop is not stressed.
- There are many species of nematodes that feed on popcorn. Dagger and spiral nematodes may be the most common and widespread nematodes. Needle nematode probably is the most damaging, but is not widespread. The most important species that is a parasite on popcorn is the lesion nematode.

**Nematicides:**

- ★ Many effective nematicides have been removed from the market and very few new nematicides are being developed, but a few compounds (including some soil insecticides) are still labeled for control of plant-parasitic nematodes on field corn.

**Pipeline pest management tools:**

- ★ None

**Other pest management aids:**

**Tillage and field sanitation effects**

- ★ Not effective for this pest

**Crop rotation**

- ★ Not effective for this pest

**Adjust Plant/harvest dates**

- ★ Not effective for this pest

**Resistant Hybrids**

- ★ Not available for this pest

## References:

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# Appendix A New Pest Control Technologies

The following new chemistries are being investigated for popcorn.

| **Chemical Name** | Trade Name | Activity | Chemistry | Registration Status |
|---|---|---|---|---|
| Spinosad | Success, Spintor | Insecticide | Macrocyclic lactone | Registered |
| Dimethenamid | Frontier | Herbicide | Chloroacetamide | Registered |
| Prosulfuron | Peak | Herbicide | Sulfonylurea (ALS Inhibitor) | Registered |
| Sulfosulfuron | Maverick | Herbicide | Sulfonylurea (ALS Inhibitor) | Pending |
| Dimethomorph | Acrobat | Fungicide | Cinnamic acid derivative | Pending |
| Fludioxonil | Maxim, Scholar | Fungicide | Phenylpyrrole | Registered |
| Kresoxim-methyl | Sovran, Cygnus | Fungicide | Strobilurin | Pending |
| Mefenoxam | Ridomil Gold | Fungicide | Active isomer of metalaxyl. | Registered |
| Propiconazole | Tilt, Orbit | Fungicide | Triazole | Registered |
| Quinoxyfen/DE795 | Arius, Quintec | Fungicide | Quinoline - Disrupts early cell signaling activities | Potential |
| Fenpropimorph | | Fungicide | Morpholine | International* |
| Picoxystrobin | ZA 1963 | Fungicide | Second generation strobilurin. | Potential |
| Famoxadone | Famoxate | Fungicide | Oxazolidinedione | Pending |
| Iodosulfuron | AE-1715 | Herbicide | Sulfonlyurea (ALS Inhibitor) | International |
| Cyfluthrin | Baythroid | Insecticide | Pyrethiod | Pending |
| Deltamethrin | Decis | Insecticide | Pyrethiod | Pending |
| Esfenvalerate | Asana | Insecticide | Pyrethroid | Registered |
| Lambda-Cyhalothrin | Karate, Warrior | Insecticide | Pyrethroid | Registered |
| Tebupirimphos | Aztec (a combination product with cyfluthrin) | Insecticide | Organophosphate | Registered |
| Tefluthrin | Force | Insecticide | Pyrethroid | Registered |
| Zeta-cypermethrin | Fury, Mustang | Insecticide | Pyrethroid | Pending |
| Cinnamaldehyde | Cinnacure, Cinnamite | Fungicide | Cinnamaldehyde (Natural Product) | Registered |
| Fluquinconazole | Jockey, Castellan | Fungicide | Triazole | |
| Peroxyacetic Acid | | Fungicide | Peroxyacetic Acid | Registered |
| Glyphosate | Roundup | Herbicide | Isopropylamine salt | Pending |

*International= being evaluated for use on popcorn in another country.

## Appendix B Herbicides Modes of Action

**ALS-inhibitors and amino acid derivatives**
inhibits amino acid synthesis (ALS acetolactate synthetase) which is first step in amino acid synthesis (proteins not replenished & growth ceases): flumetsulam, halosulfuron, imazapyr, imazethapyr, nicosulfuron, primisulfuron, rimsulfuron
**PSII inhibitors (non-mobile)**
prevent electron transfer, excess electrons develop and results in formation of singlet oxygen O2- and HO- which destroys lipid membranes: bentazon, bromoxynil
**PSII inhibitors (mobile)**
blocks electron flow in PSII (Hill) reaction, preventing electron transfer, excess electrons develop and breakdown cells: atrazine, cyanazine, metribuzin, simazine
**Root-mitosis- inhibitors**
disrupt mitosis by inhibiting tubulin-spindle apparatus formation during cell splitting: pendimethalin
**Shoot inhibitors**
inhibition of lipid synthesis but other processes also active: acetochlor, alachlor, dimethenamid, EPTC, flufenacet, metolachlor
**Growth-hormone- regulator**
stimulates irregular cell growth and may loosen connections between cell walls, other processes also active: 2,4-D, clopyralid, dicamba
**Pigment synthesis inhibitor**
affect enzymes of carotenoid synthesis which prevents chlorophyll formation (unknown target enzyme):: impinging light develops free radicals for further destruction :isoxaflutole, mesotrione
**Protein synthesis inhibitors**
inhibits amino acid synthesis EPSP synthase (amino acids are not replaced): glufosinate, glyphosate
**ACCase inhibitors**
inhibits acetyl CoA carboxylase with lipid synthesis in meristem primarily affected, lipids not replenished: sethoxydim, quizalofop, fluazifop, clethodim.
**PPO inhibitors**
inhibition of protoporphyrinogen oxidase (PPO) results in development of free radical and lipid: peroxidation (breakdown of chloroplasts ect)

## Appendix C Fungicide Modes of Action

Information abstracted from:
http://www.ndsu.nodak.edu/instruct/gudmesta/lateblight/Modified/PDFdocuments/fungicides.PDF

| | | |
|---|---|---|
| **Protectants** | | |
| Sulfur | Thiolux DF, Liquid Sulfur Six, Microthiol Special | blocks enzymes and stops respiration |
| Dithiocarbamates | ferbam, thiram, ziram | interfere with oxygen uptake and inhibition of sulfur containing enzymes |
| Ethylenebisdithio-carbamates EBDCs | mancozeb Manzate, Dithane M-45, Penncozeb, Fore, maneb Dithane M-22, zineb Zineb | breaks down to cyanide, which reacts with thiol compounds in the cell and interferes with sulfhydryl groups |
| Organometallics | Copper sulfate, copper hydroxide, cupric hydroxide, copper oxychloride (Kocide, COC, Blue Shield, Basic Copper, TopCop | prevent spore germination |
| Organometallics (other) | triphenyltin hydroxide (Super tine, Agritin, Triple Tin) | destroys cell membranes, inhibits respiration |
| Phenylpyroles | fludioxonil (Maxim), fenpiclonil | affects membrane transport |
| Phenylthalimides | captan (Captan 50WP, Captan 80WP, Captec 4L) | degrades to thiophosgene which inhibits fungal enzymes |
| Substituted Benzenes | Pentachloronitrobenzene or PCNB (Terraclor, Turfcide, Blocker)<br>Chlorothalonil (Bravo, Daconil, Echo, Evade, Equus) | PCNB induces lysis of mitrochondrial membranes chlorothalonil inhibits sulfur-containing enzymes |
| Pyridinamines | fluazinam (Shirlan, Omega) | non-specific respiration inhibition (though different from azoxystrobin) |
| Benzothiazole | acibenzolar-S-methyl (Actigard) | systemic acquired resistance-no direct toxicant properties |
| **Curatives** | | |
| Acetimides (Cyano-oximes) | cymoxanil (Curzate) | inhibition of RNA synthesis, different from metalaxyl |
| Aluminum tris-0-ethyl phosphonate | fosetyl-Al (Aliette) | stimulates defense reactions within the plant and promotes synthesis of phytoalexins, slow acting |
| Anilinopyrimidines | cyprodinit (Vangard) pyrimethanil | methionine biosynthesis inhibitor and inhibits protease secretion by fungi |
| Benaznilides | flutolanil (Moncut, Prostar) | inhibits fungal respiration at succinated dehydrogenase complex |
| Benzimidazoles | benomyl (benlate), Thiabendazole (Mertect), thiphanate-methyl (Topsin-M) | inhibition of mitosis by preventing polymerisation of beta-tubulin |

| | | |
|---|---|---|
| Benzothiadiazoles | CGA245704 | stimulate defense reactions within the plant (SAR)system acquired resistance |
| Carbamates | propamocarb hudrochloride (Tattoo, Banol, Previcun) | interferes with membrane biosynthesis |
| Cinnamic Acid Derivatives | dimethomorph (Acrobat) | inhibition of cell wall biosynthesis |
| Dicarboximides | iprodione (Rovral, Chipco 26019), vinclozolin (Ronilan) | unknown |
| Phenylamides (Acylalanines) | metalaxyl (Ridomil, Subdue, Apron) mefenoxam (Ridomil Gold, Subdue Gold, Apron XL) fluoronil (Ultraflourish) | RNA synthesis inhibition |
| **Sterol inhibitors** | | |
| Triazoles | triadimefon (Bayleton), triadimenol (Baytan), propiconazole (Tilt, Orbit, Break, Banner), myclobutanil (Rally, Nova, Eagle), cyproconazole (Sentinel, Alto), tebuconazole (Folicur, Elite, Raxil), fenbuconazole (Indar, Enalbe, Govern), difenconazole (Dividend), hexaconazole (Anvil), tetraconazole (Emminant), flusilazone, epoxiconazole, flutriafol (Impact) | inhibition of sterol biosynthesis (demethylation inhibitors DMI) |
| **Strobilurins** | | |
| Beta-methoxyacrylates | azoxystrobin (ICIA5504, Abound, Quadris, Heritage) trifloxystrobin (Flint) | disruption of electron transport in cytochrome bc1 complex |
| Oximinoacetates | kresoxim-methyl (Stroby DF) | disruption of electron transport in cytochrome bc1 complex |

## Appendix D Insecticide Modes of Action

In the current regulatory climate, organophosphate insecticides are coming under more and more restrictions. As a rule, they are much more toxic to mammals than the newer types of insecticides such as the benzimidazoles and avermectins.

Most of the common insecticides and anthelminthics used (except the growth regulators and benzimidazoles) are neurotoxins -- they kill by either preventing, inhibiting, or augmenting nerve impulse transmissions. The growth regulators and benzimidazoles are hormone mimics or inhibitors of metabolic enzymes.

The main synaptic neurotransmitter (a molecule which transmits signals across the synapse between nerve cells or between nerve cells and muscle cells) is acetylcholine. After it has carried the signal across a synapse, it is degraded and inactivated by an enzyme in the neuron called "acetylcholinesterase" or simply "cholinesterase". A compound which either acts like acetylcholine or binds to the cholinesterase will cause excessive transmission of impulses across the synapse and thus paralyze the muscles involved. Conversely, a compound which binds to the acetylcholine receptor site can block and therefore prevent transmission of impulses across the synapse and also paralyze the muscles involved. These compounds are known as antagonistic neurotransmitters.

**Growth Regulators**

These compounds are either hormone mimics or enzyme inhibitors. Some (like methoprene), are analogs to insect juvenile hormones. Their presence causes the larvae of target insects to remain in a juvenile state. Unable to molt, the larvae eventually die. Since they act like hormones, they are effective at very low concentrations, and can be applied at very low rates. Since most vertebrates (all mammals) do not have receptors for such hormones, they are unaffected by these compounds. The low effective rate and low mammalian toxicity make them very safe for mammalian applications. Aquatic crustaceans and some fish, though, seem to have analogous hormones and are quite sensitive to these compounds.

Enzyme inhibitors bind to important enzymes in metabolic pathways and prevent them from functioning. One of the most common types of enzyme inhibitors, bind to enzymes involved in the synthesis of chitin, a key protein in arthropod exoskeletons. Diflubenzuron is an example of this type of compound.

**Benzimidazoles**

These pesticides are also enzyme inhibitors. They inhibit enzymes involved in assembly of glucose transport structures in the intestines of target pests (roundworms and flatworms). Not being able to absorb glucose, the worms eventually die. Mammals do not have these enzymes and are thus relatively insensitive to these compounds. (Some, such as fenbendazole, also have anti-fungal activity.)

**Avermectins**

Avermectins are a group of compounds obtained from a common soil fungus (actinomycete). They act on GABA (gamma-aminobutyric acid) receptor sites. GABA is an inhibitory neurotransmitter and acts to limit the transmission of nerve impulses. The avermectins act to keep open a chloride ion channel which controls the GABA receptor. Thus, when avermectin molecules are present, the neuron continues to fire at a high rate, which paralyzes the muscles involved. The only place in mammals where GABA and GABA receptors are found is in the brain (where it is the major inhibitory neurotransmitter). Since avermectins cannot cross the blood-brain barrier except at levels much higher than normal therapeutic levels, these compounds are relatively non-toxic to mammals. In insects and roundworms, GABA receptors are found distributed throughout their nervous systems, particularly in skeletal and body muscles.

**Organophosphates**

Organophosphate compounds cause an irreversible modification of acetylcholinesterase. When this enzyme is deactivated, acetylcholine in synapses is not broken down after its use and continues to cause the receiving neuron to fire. This leads to convulsions and paralysis of the muscle cells involved. Since acetylcholine is the main neurotransmitter between nerve cells in all type of mammalian tissues, these compounds are usually quite toxic to mammals as well as to other vertebrates and insects. In some cases, mammals have enzymes that can degrade certain organophosphate compounds (such as malathion), and these particular compounds are not quite as toxic as the others.

**Pyrethroids**

Pyrethrum, the original pyrethroid, was obtained from flowers of a tropical chrysanthemum species. However, most pyrethroids currently in use are synthetic, though their basic structure is patterned after natural pyrethrins. They act on the axon of the neuron on the transmitting side of a synapse. They either cause a sodium ion channel on that axon to stay open too long or they prevent it from closing. This causes the neuron to either transmit a very weak pulse or to fire repetitively. The muscle cells involved thus do not receive the nerve impulse or they are overexcited. In either case, the muscles are paralyzed. Mammalian sensitivity is much lower than that of insects because of fewer binding sites and because the pyrethroids can be broken down by esterases in mammalian cells.

**Imidothiazoles**

The imidothiazoles bind to acetylcholine receptors on the receiving side of a synapse. This, of course, causes the receiving neuron to fire just as if acetylcholine had bound to the site However, the imidothiazole molecule cannot be broken down and inactivated by cholinesterase so the nerve cell continues to fire. This results in spastic paralysis of the muscle cells involved.

**Pyrimidines**

These have the same mode of action as the imidothiazoles (acetylcholine mimic)

**Organochlorines**

Work by overstimulating the nervous system causing convulsions and uncontrolled muscle movements. These products are not cholinesterase inhibitors. Lindane is an example of an organochlorine.

**Carbamates**

These have essentially the same mode of action as organophosphate insecticides. Carbofuran is an example of a carbamate insecticide.

# Appendix E. Active ingredient and mode of action table for listed pesticides.

| | Active Ingredient (ai) | Trade name | Class |
|---|---|---|---|
| Insecticides | *Bacillus thuringiensis* | Dipel, MVP, Javelin | Biological |
| | Bifenthrin | Brigade, Capture | Pyrethroid |
| | Carbaryl | Sevin | Carbamate |
| | Carbofuran | Furadan | Carbamate |
| | Chlorethoxyfos | Fortress | Organophosphate |
| | Chlorpyrifos | Lorsban | Organophosphate |
| | Cyfluthrin(+Tebupirimphos) | Aztec, Baythroid | Pyrethroid + Organophosphate |
| | Diazinon (+Lindane) | Kernel Guard | Organophosphate + Organochlorine |
| | Dimethoate | Cygon | Organophosphate |
| | Esfenvalerate | Asana | Pyrethroid |
| | Fipronil | Regent | Phenylpyrazole |
| | Imidacloprid | Gaucho, Gaucho Xtra, Prescribe | Chloronicotinyl |
| | Lambda-cyhalothrin | Warrior | Pyrethroid |
| | Lindane (+Diazinon) | Kernel Guard | Organochlorine + Organophosphate |
| | Methyl Parathion | Penncap-M | Organophosphate |
| | Methomyl | Lannate | Carbamate |
| | Permethrin | Ambush, Pounce | Pyrethroid |
| | Permethrin | Kernel Guard Supreme | Pyrethroid |
| | Phorate | Thimet | Organophosphate |
| | Tebupirimphos + Cyfluthrin | Aztec, Baythroid | Organophosphate + Pyrethroid |
| | Spinosad | Tracer | Biological (Naturalyte) |
| | Tefluthrin | Force, Force ST, Proshield | Pyrethroid |
| | Terbufos | Counter | Organophosphate |
| Fungicides | Azoxystrobin | Quadris | Triazole |
| | Captan | Captan | Phenylthalimide |
| | Chlorothalonil | Bravo | Substituted Benzene |
| | Fludioxonil | Maxim | Phenylpyrole |
| | Mancozeb | Dithane, Mancozeb | Ethylenebisdithiocarbamates |
| | Metalaxyl | Apron | Phenylamide |
| | Propiconazole | Tilt | Triazole |
| | | | **Class fb HRAC Mode of Action** |
| Herbicides | 2,4-D | Many on the market | Chlorinated phenoxy O |
| | Acetochlor | Doubleplay, Harness, Surpass, (in FulTime) | Acetamide K3 |
| | Alachlor | Lasso, Micro-tech | Acetamide K3 |
| | Atrazine | Atrazine, Extrazine, (in Laddok, Marksman) | Triazine C1 |
| | Bentazon | Basagran, (in Laddok) | Other C3 |
| | Bromoxynil | Buctril, Contour, (in Buctril+Atrazine) | Other C3 |
| | Butylate | Sutan Plus | Thiocarbamate N |
| | Carfentrazone | Aim | Aryl triazolinone E |
| | Clethodim | Select | Cyclohexanediones A |
| | Clopyralid | Hornet, Scorpion, Stinger | Picolinic acid O |
| | Clomazone | Command | Isoxazolidinone F3 |
| | Dicamba | Clarity, (in Celebrity, Distinct, Marksman, NorthStar) | Benzoic acid O |
| | Diflufenzopyr | Distinct, | Semicarbazone P |
| | Dimethenamid | Frontier, Outlook | Acetamide K3 |
| | EPTC | Doubleplay, Eradicane | Thiocarbamate N |
| | Fluazifop | Fusilade | Aryloxyphenoxyproprionates A |
| | Flumetsulam | Accent Gold, Hornet, Python | Sulfonanilides B |
| | Flumiclorac | Resource | N-Pheylphthalimide E |
| | Flufenacet | Axiom | Oxyacetamides K3 |
| | Glufosinate | Liberty | Phospinic acid H |
| | Glyphosate | Roundup | Glycines G |
| | Halosulfuron | Permit | Sulfonylurea B |
| | Imazapyr | Lightning | Imidazolinone B |
| | Imazethapyr | Contour, Lightning, Resolve | Imidazolinone B |
| | Isoxaflutole | Balance | Isoxazoles F2 |
| | Mesotrione | Callisto | Triketones F2 |
| | Metolachlor | Dual II Magnum | Acetamide K3 |
| | Metribuzin | Sencor, Lexone | Triazinone C1 |
| | Nicosulfuron | Accent, Accent Gold, Basis Gold | Sulfonylurea B |
| | Paraquat | Paraquat | Bipyridylium, Dipyridylium D |
| | Pendimethalin | Pentagon, Prowl | Dinitroaniline K1 |
| | Primisulfuron | Beacon, (in Exceed, NorthStar, Spirit) | Sulfonylurea B |
| | Prosulfuron | Exceed, Spirit | Sulfonylurea B |
| | Pyridate | Tough | Phenylpyridazine C3 |
| | Quizalofop | Assure | Aryloxyphenoxyproprionates A |
| | Rimsulfuron | Basis, Basis Gold | Sulfonylurea B |
| | Sethoxydim | Poast | Cyclohexanediones A |
| | Simazine | Princep | Triazine C1 |
| | Thifensulfuron methyl | Basis | Sulfonylurea B |

## Appendix F. Glossary

**A.I.** Abbreviation for active ingredient: the amount of pesticidal compound in a formulated product.
**Adventitious**: The secondary root system of corn which forms above the ground level. Also known as brace roots.
**Air-assist**: An application method which uses channelized air to assist the delivery of spray droplets.
**Annuals**: Plants which germinate, flower, and produce seed within a one year period.
**Anti-drift**: Chemicals added to liquid sprays to reduce the number of fine droplets which have a high potential for drift.
**Application:** The placement of a pesticide in the field by means of a liquid spray or granular form.
**Applicator**: A farmer or independent agent for hire who applies a pesticide.
**At-planting**: The time the crop is planted.
**Beneficials**: Insects which are considered to be generally advantageous to the crop.
**Biochemical**: A chemical process that occurs within a living organism.
**Biodegradation**: Breakdown of a pesticide by living organisms.
**Biotechnology**: The technology which involves insertion of genetic material into one organism from another organism not closely related.
**Biotype:** Groups of individuals within a species that bear genetic traits that vary in minute, but identifiable ways from the larger population.
**Booms:** The extensible arms of a mechanical sprayer.
**Broadleaf**: Dicotyledonous plants that are typically characterized by netted veins and non-linear formed leaves.
**Burn-down**: Herbicides used to kill vegetation that is present and actively growing at the time of application.
**Carryover**: A pesticide that when applied to one crop, persists in the soil to negatively affect crops in succeeding plantings.
**Chemigation**: Pesticide application directly to a crop by injection directly into an irrigation system.
**Commodity Profiles**: Documents describing the general pest/pesticide situation faced by producers of a crop.
**Conidia** : An asexual fungal spore.
**Cross-resistance**: Development of a resistance mechanism to one pesticide that confers resistance to another pesticide.
**Diapause:** A period of physiological inactivity occurring at one stage in the life cycle of an insect.
**Dormancy:** A period of quiescence, enforced or voluntary, where active development ceases.
**Edaphic:** Of or relating to the soil.
**Inbreds**: Breeding stock intentionally crossed with parent lines to amplify desirable traits.
**Meristematic:** Tissue in plants from which new growth originates.
**Mycelium**: Threadlike, vegetative tubes of a fungal body.
**Mycotoxins:** Toxins developed from fungal organisms.
**Oviposit**: Deposition of insect eggs directly to a surface or region.
**Perennials:** Plants which live for three or more years.
**Pheromone:** Chemical compounds which convey behavioral signals.
**PHI**: Pre Harvest Interval: The required time between a pesticide application to a commodity and the harvest of that commodity.
**Post-emergence:** Pesticide applied after the crop has emerged.
**Pre-emergence:** Pesticides applied before the crop has emerged.
**Pupae:** Pre-adult insect developmental stage.
**REI**: Restricted-Entry Interval: Required time between an application and worker entry into a treated field.
**Restricted Use Pesticide:** Pesticides which must only be applied by a licenced applicator.
**Rhizomes**: Underground rooting structures of perennial plants from which new shoots may emerge.
**Silking:** Corn stage where the silks are fresh and emerging from the corn ear.
**Smartbox:** Enclosed pesticide containers attached directly to corn planters, reducing exposure of operators to the pesticide.
**Stacked Traits**: The inclusion of more than one genetic trait in one plant from organisms not closely related.
**Strip till**: Tilling a small strip of soil within which the crop row is planted. This permits the greater portion of the field to remain untilled.
**Systemic**: Having an action or effect transmitted throughout the entire plant.
**Systems-based:** Involving the use of multiple approaches to solving a single problem.
**T-banded:** Application of an insecticide in a narrow band directly over the row and down into the seed furrow.
**Tassel:** The corn stage where the tassels begin to emerge from at the top of the plant.
**Teliospore:** Rust spore resting stage that germinates at the end of winter.
**TMDL**: Total Maximum Daily Load: The maximum permissible exposure limit to environmental contaminants.
**Tolerant**: An organism which tolerates to some degree, but is not totally resistant to, a non-benign agent.
**Transgenic**: Insertion of genetic material into one organism from another organism not closely related.
**Whorl:** Funnel shaped leaf formation found at the top of the corn plant and many other grasses.