Field Corn
Pest Management Strategic Plan
North Central Region

14 August 2002

Compiled on the
22nd and 23rd of January, 2002
at a Workshop held in Champaign, Illinois
and on the
28th of February and 1st of March
at a workshop held in Sioux City, Iowa.

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Strategic Plan Development: An Overview

The purpose of a Pest Management Strategic Plan is to provide a document that communicates the role of pesticides and pest management strategies in control of crop pests from an industry perspective, with cooperation and verification from corn pest management specialists. While this information is primarily used by the Environmental Protection Agency (EPA), it also provides to the USDA, Land Grant Universities, and pest management stakeholders a prioritized "to do" list of research, education, and regulatory issues. Strategic Plans may also be helpful to the field corn industry as a means of evaluating progress on those issues.

This document has been prepared to convey to the reader the pest management challenges confronting Midwestern field corn producers. Though it is not all-inclusive, it is meant to be generally representative of corn pest management in the North Central Region.

This initial version of the field corn Pest Management Strategic Plan is based on information assimilated from individual state's field corn crop profiles. The document was further developed from input gathered from producers, consultants, and other technical experts attending two workshops. For the eastern portion of the Corn Belt a workshop was held in Champaign, Illinois on the 22nd and 23rd of January, 2002. Another workshop was held on the 28th of February and 1st of March, in Sioux City, Iowa for stakeholders in the western region of the Corn Belt. In addition to providing input on pests and pest control methodologies, attendees identified research, education and regulatory issues that impact producer profitability and environmental quality. The final task of the meeting attendees was to prioritize the issues that they thought were the most critical to corn pest management in the Midwest.

Data completeness and accuracy: The intent of this report is to provide the EPA with the pest management perspectives of field corn producers, consultants, and other pest management specialists. As such, it primarily reflects the comments and inputs of those parties who attended the workshops. As with any group of individuals, the scope of knowledge as well as opinions of participants vary greatly, and in its current form this document captures that scope and diversity.

Another factor which affected the completeness of information was the method used to collect information during the meetings. Time constraints typically dictated that the first pests listed in the insect and disease categories received more attention than those listed later. The weed section was handled differently because of the large number of weeds and herbicides to be considered. Although some efforts were made during the review process to correct the lack of balance, the uneven completeness of data remains an artifact of our procedure. The editors and reviewers have taken significant measures to excise faulty or misleading information, but it has not been our intent to remove or alter information which was provided at the workshops that does not harmonize with "conventional wisdom". This Strategic Plan should be viewed as a work in progress; future versions will undoubtably result in an improved product.

Regional differences: Throughout the text of this document an effort has been made to identify regional differences in pests, their treatment, and the research, educational, or regulatory issues producers in those regions would like to see addressed. These differences are found in bold type in the text.

Efficacy ratings for pesticides: Generally pest control ratings for various pest management practices are given throughout the text as fair, good, or excellent. The absence of an indication of control for a pest suggests that control is poor or that use of the product by workshop members or their clients was insufficient to provide a basis for rating. For the section on weeds the terms Fair, Good, and Excellent are loosely correlated with the percent of weed control achieved. For annual weeds these ratings generally equate to the following percentages: Excellent: 90-99 percent control, Good: 85-95 percent control, and Fair: 75-90 percent control. As indicated in the weed section, ratings for control of perennial weeds are based on the producer expectations that more than one treatment per season is necessary for effective control. For these ratings, and for treatments used for many insects and some plant diseases, no direct correlation exists between percent control and the terms used to indicate a level of control. However, for most pest management practices it is perhaps reasonable to suggest that a 'fair' rating is considered marginally acceptable to producers, while 'excellent' consistently reduces the pest to non-economic levels with a single treatment.

Executive summary:

Corn (*Zea mays* L.) defines agriculture in the midwestern United States. With approximately 72 million acres in annual production and average per acre yields of 135 bushels per acre, the midwestern states produce 90% of the 9-10 billion bushels of annual U.S. production. The importance of corn, not only to the United States but to the world, as a predominant feed and industrial grain cannot be overstated. While agricultural production is expanding worldwide as virgin grasslands and forests are converted to agriculture, the vast majority of this new production is incapable of supporting corn production. The midwestern United States represents the largest contiguous agroecosystem in the world capable of supporting corn production. U.S. Corn Belt agriculture produces 19 billion dollars of farmgate income annually with additional value derived from meat production, ethanol, sweeteners, industrial by-products, and other uses. Field corn production, therefore, is inextricably intertwined with the quality of life and economic well being and security of the Midwest. The businesses and support system of the communities within this region are closely linked to the agricultural sector and there is seldom a pain felt by the farmer that is not perceived by the farm community with equal impact. Nearly every local industry or service, from schools to banks to department stores, is tied to farm economics. A failure in the farm sector, in particular a failure in corn production, means a loss of income, businesses, and jobs throughout all communities. With profit margins at historic lows, producers are looking for opportunities to reduce the costs and risks of corn production to maintain their economic viability. This Pest Management Strategic Plan offers a glimpse into the opportunities and challenges producers face in trying to maintain a profitable and secure industry. The story that unfolds suggests that Midwestern agriculture is in transition, and that much of this transition is occurring in pest management.

Part of the transition producers face is that of the environmental challenges brought about by the impact of their pest management practices on large farms. "....farm units of 10,000 acres and up are already common in Great Plains states and could easily dominate cash grain production in the near future.....Research investments are needed to address environmental concerns that severely constrain the growth of the corn industry. The industry needs financial support so that producers can afford to safeguard water quality [Italics added]" (Evolution of Corn Belt Agriculture, NCGA, Feb, 2002).

With the enactment of "The Farm Security and Rural Investment Act of 2002" and its infusion of $17.1 billion for environmental stewardship programs such as EQIP and CSP, now is the time to assess the pest management needs and priorities of corn-belt farmers and prepare a plan of action. This report provides details of specific needs as indicated by field corn producers who attended two separate workshops in early 2002. Workshop participants provided a list of research, regulatory, and educational priorities upon which the industry can focus. These issues involved an expression of need for new technologies as well as strong sentiment to retain current technologies that are working well.

Within the context of corn pest management, workshop participants indicated that they face two precipitous events; the possible loss of atrazine as the basic tool of weed management, and the increasing widespread adoption of Bt corn hybrids for control of corn rootworms, European corn borer and black cutworm; all key insect pests that are risk drivers for insecticide use. The highest priority among producers in both workgroups was the need to maintain atrazine registrations. Atrazine continues to be the best general prophylactic and curative treatment for annual weeds in field corn with a utility that is greatly enhanced by its low cost. Producers felt it was of utmost importance to communicate to regulatory agencies their considerable stewardship efforts with this compound and their willingness to continue to improve those efforts in the future.

The topic of Bt hybrids and transgenic crops in general was also common in discussions. Producers indicated that raising the visibility of the benefits of Genetically Modified Organism (GMO) crops must be a priority. Producers see GMO crops as a logical means of improving the quality of their products as well as protecting the environment. Difficulties such as those associated with StarLink must be avoided at all costs and growers, seed companies, and regulatory agencies should work together to insure that similar events do not occur.

A Prioritized List of Research, Regulatory, and Educational Needs

Research (East Region)	Regulatory (East Region)	Education (East Region)
Research long term, large-scale systems approaches, including economics, yield and multi-pests, of no-till corn production systems. Increased pest problems under no-till are perceived to be a significant factor in the decrease in no-till corn acres.	Maintain current registered uses of atrazine and the triazine compounds for corn production.	Educate consumers and regulators on the vital role of atrazine to the corn industry. This includes conveying an understanding of its many benefits to growers; applicator safety, crop safety, synergistic effect with other products, wide spectrum of activity, residual activity, burndown activity, cost effectiveness, efficacy, and lack of suitable alternatives for some uses.
The development of consumer oriented (output) traits through biotech is seen as a means of breaking down consumer resistance to much needed agronomic GMO traits.	Find ways to assist the EPA in using current production practices and real world data to evaluate products undergoing re-registration.	Educate regulators and public policymakers that water quality issues are being addressed through proactive environmental stewardship programs throughout the Corn Belt.
Continue and increase support to public and private plant breeders to develop hybrid resistance for all corn diseases. Growers perceive this as a first line of defense for maintaining profitability.	Harmonize domestic biotechnology regulatory processes with foreign customers as necessary to remove trade barriers to U.S. corn exports.	Educate regulatory agencies of atrazine's role as an important weed resistance management tool.
Research is needed on anti-drift products, nozzles, etc/ to prevent off-site movement of sprays		Educate the public on the benefits of adoption of GMOs to include advantages to production and the environment.
Research is needed to evaluate current stewardship programs in a systems approach. Do they compromise the growers ability to control weeds by prohibiting the use of some cultural treatments unnecessarily? Do restrictions on tillage encourage winter annual weeds and a concomitant increase in the need for herbicides and insecticides?		Educate growers about use of systems approaches that mitigate herbicide contamination of ground and surface waters so that herbicides are not listed as a pollutant on a state's TMDL list.

Research (West Region)	**Regulatory (West Region)**	**Education (West Region)**
Better understand weed biology and ecology. This is particularly important with regards to understanding the development of weed resistance and weed shifts that result from weed management practices such as the use of glyphosate and glufosinate-tolerant crops.	Retain low cost herbicides in the market, especially atrazine and 2,4-D. Keeping cost-effective products that meet a wide range of needs and add versatility to management options is critical, particularly in broadening the spectrum of control of the other products.	Enhance the timeliness of the communication process to growers and crop advisors regarding economic thresholds, degree-days and other predictive models, and effective products to use.
Improve our understanding of wireworm and white grub biology. Also needed is supportive research to determine scouting techniques and predictive tools for these increasingly important pests.	Simplify labels so that they are more consistently and directly written, leading to better compliance by applicators. Also include potential long-term human health affects on labels, not just the MSDS.	Better inform growers regarding the use of disease-resistant hybrids. It is generally perceived that growers are underutilizing hybrids with advanced disease resistance and that educational program may provide significant benefits to growers.
Encourage ongoing support for private and public efforts to improve corn's genetic base, particularly for disease management. As a low margin crop, breeding is acknowledged as the linchpin for maintaining profitability.	Encourage development of new pesticides for field corn, particularly in situations where GMO hybrids are likely to be widely used. A broad range of modes of action continues to be essential.	Better inform growers regarding the performance and role of adjuvants on herbicide efficacy. Adjuvants play an important role in herbicide efficacy and their proper selection and use is viewed as a means of enhancing profitability.
Determine methods of containing drift and reducing off-site movement of herbicides, and communicate precautionary information in a more effective manner	Registration of Bt corn for corn rootworm management is a high priority. However, the development of resistance management plans, so that the technology retains its effectiveness, must be a concomitant effort	

Recommendations not otherwise categorized as research, regulatory, or educational priorities.

I. Record Keeping: At the western region workshop, record-keeping was mentioned as a key to present-day and future pest management efforts in field corn production. Effective field records enable the producer to document where pest infestations have occurred as well as where different pest management tactics have been employed. Armed with this information, the producer can make informed decisions about solving current problems. A good record system needs to thoroughly track farm practices and be easy to use, in turn helping to integrate farm management practices. The need for good field records is heightened as new technology, especially the use of transgenic hybrids, is used on the farm.

II. User friendly Pesticide Labeling: Participants at the western region meeting indicated that pesticide labels need to be more consistent so that directions regarding safety equipment, restricted-entry intervals, and pre-harvest intervals are more easily understood. It was suggested that a consistent index be provided for all agricultural labels that would serve to quickly identify commonly used information. Identifying pesticide mode of action is becoming more important as producers are advised to rotate modes of action. It was suggested that each label might provide clear and easily understood Mode-of-Action designations for each product.

III. Maintenance of a Viable Information Infrastructure: Both the western and eastern region workshop participants discussed the importance of a viable research and information dissemination infrastructure. In general, there remains a pressing need for up-to-date research and an effective information delivery system. Although land grant institutions are generally a trusted source of research-based information, many challenges have resulted from dwindling resources. The transfer of research findings to producers and professional crop advisors, through both conventional and non-conventional delivery systems, will be key to the successful implementation of economically and environmentally effective management strategies. Timely access to this information resource is important, and any steps to enhance crop decision maker's immediate access to the research data is of critical importance.

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Corn Production and Pest Management: Current and Future Trends

General Production Information

- Corn is grown throughout the North Central Region. Approximately 70 million acres of corn are grown (see Table 1) with a farmgate value of $19 billion annually.
- Planting may begin as early as mid March in the southern areas of the Corn Belt and the middle of May in northern areas, such as Minnesota and North Dakota.
- In areas with concentrated dairy, beef, or hog production, corn is primarily used for feed grain. In areas more remote from livestock industries, corn may be processed for oil, sweeteners, and corn meal or shipped to domestic feed grain or export markets. Corn may be ensiled, but such use is primarily in areas where dairy or beef cattle are fed. Approximately 60 percent of all corn is consumed by livestock and the remaining 40 percent is processed for use by humans.
- Although seed corn production is not specifically covered in this document there are many similarities between the pests and pest control measures used to control them. There are some significant differences, however, as inbred lines tend to be more susceptible to many pests and the higher value of the crop can justify greater pesticide use.
- Throughout the Midwest corn fields are closely managed and there is a general lack of tolerance for pests by producers. This lack of tolerance is often exacerbated by the level terrain of much of the Corn Belt and the ease with which uneven stands or weeds can be seen from the field's edge.

Table 1. Corn for Grain: Area Harvested, Yield, and Production by State and United States, 2000 and Forecasted October 1, 2001.

	Area Harvested		Yield per Acre		Production	
	2000	2001	2000	Oct 2001	2000	2001
State	1,000 Acres		--------Bushels--------		- 1,000 Bushels -	
IL	11,050	10,750	151	149	1,668,550	1,601,750
IN	5,550	5,750	147	160	815,850	920,000
IA	12,000	11,500	145	141	1,740,000	1,621,500
KS	3,200	3,100	130	132	416,000	409,200
KY	1,230	1,107	130	142	159,900	156,200
MI	1,970	1,950	124	92	244,280	179,400
MN	6,600	6,200	145	129	957,000	799,800
MO	2,770	2,570	143	136	396,110	349,520
NE	8,050	7,900	126	138	1,014,300	1,090,200
ND	930	660	112	110	104,160	72,600
OH	3,300	3,150	147	143	485,100	450,450
SD	3,850	3,400	112	116	431,200	394,400
WI	2,750	2,600	132	128	363,000	332,800
US	72,732	69,191	137	136	9,968,358	9,429,543

Source: http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bb/2001/crop0801.txt

Current cultural practices

- Corn is typically grown in a rotation with soybeans and less often with wheat, sorghum, or alfalfa. About 30 percent of the corn in the Midwest is grown as continuous corn.
- No-till is practiced on about 20 percent of the corn acreage annually, and some form of conservation tillage practiced on another 20 to 30 percent. Because many producers feel that pest control measures tend to be less effective when corn is no-till planted, the use of no-till for field corn has not appreciably increased for several years.
- About 30 percent of the acreage is cultivated with a row cultivator and an estimated 30 percent is rotary hoed annually.
- Approximately half of all pesticides are applied by the farmer and the other half are applied by commercially licensed dealers and applicators. In general there is a trend for larger farmers to apply a greater proportion of their own herbicides than would producers with small farms.
- Approximately 90% of insecticides used on field corn are for soil insects and are applied by the farmer at planting with planter box applicators. The use of insecticidal seed treatments, as well as the use of liquid formulation insecticides, is becoming more common.
- Fungicide use is generally limited to the seed treatments that have been applied prior to purchase.

Earlier planting

- Cool soils (<50 degrees F @2" depth) during early season planting favors a high incidence of seedling diseases and a concomitant need for effective and low cost fungicides. Early planting also tends to shift weed populations toward weeds adapted to grow in cooler temperatures; lambsquarters, mustards, and smartweed species. The impact of several insect pests may also increase in earlier plantings.
- Though planting later in the season is mentioned as a pest control strategy for many of the pests listed in this document, this may not be a practical solution for producers who must take advantage of 'windows of opportunity' to till and plant fields. A delay of a few days typically will result in yield reductions and can, in some years where weather is erratic, result in total crop failure. In order to capitalize on the advantages of early planting, pests must be controlled.

Use of hybrids with GMO traits

- The use of hybrids for herbicide resistance or that express insect toxins is expected to increase, resulting in reductions in the pesticides used. Pest populations will also shift in response to the changes in herbicide and insecticide use. Overall, fields planted to varieties of corn with GMO traits are expected to have fewer weed and insect problems. An undesirable impact of this is that GMO use will raise the general standard for field cleanliness and appearance, and can result in an attitude among growers that will foster unnecessary pesticide use.
- As more GMO crops are grown, and as multiple traits are 'stacked' in hybrids, there is an increasing likelihood of confusion for growers regarding what pesticides and pesticide resistance management strategies are necessary and sufficient. This trend is likely to further enhance the role of the professional in prescribing and applying pesticides.
- There is currently a great deal of controversy over the marketability of grain with GMO traits. In 2001, with over 30 percent of all corn bearing at least one GMO trait, this has come to be a significant concern. However, many producers are looking to ethanol production as a means of avoiding some of this controversy. Because corn destined for alcohol production is not consumed by humans there is considerably less concern over this end use of GMO type corn.

Use of conservation tillage

- The Conservation Tillage Information Center (CTIC) estimates that an average of 37% of corn acres are grown under some type of conservation tillage. These estimates have been relatively steady for the past five years. However, the perception that no-till corn acres are declining, especially in the eastern portion of the Corn Belt, is prevalent. Many of the reasons were pest related. Poor stands in no-till are attributed to cool wet soils which result in a greater risk for seed decay, seedling diseases, soil insect injury, and higher weed control costs. Undisturbed soil and the presence of crop residue results in more perennial weeds, the predominance of small seeded grass and broadleaf weeds, and a protective environment for many injurious insects. These trends require an effective array of soil-applied and burn-down herbicides as well as efficacious insecticides with sufficient persistence to adequately control soil-dwelling insects. Burn-down herbicides and herbicides that persist in the soil for the 6 to 8 weeks necessary to prevent weeds from competing with the crop during establishment, will remain a high priority.

Larger farms

- The size of farming operations continues to increase. Large farms operated by a single operator require the use of efficient technologies. Wherever practical, herbicides will continue to replace time-consuming pest management practices such as tillage and row cultivation. Growers will also continue to select technologies and products that allow for single-pass weed control or otherwise reduce the need for multiple trips through the fields. This suggests a continuing preference for pre-mixes and tank-mixes with broad spectrums of control and wide application windows. Larger farms also suggest that more decisions will be turned over to professional agronomists; either those working as dealers and distributors of ag-chem products or to private consultants.

More landlord/tenant operations

- The trend toward farm ownership being passed to those that do not directly operate them is expected to continue. Farmers will compete for available rental farmland and pressure will prevail to maintain high levels of pest control based more on aesthetics and perceptions than on economic thresholds. As a result, the use of pesticides for pest control will become further decoupled from threshold-based treatment levels. The expected outcome is that post emergence herbicide applications will remain in high demand for field cleanups. Keen competition for ‘cash rent’ land is also resulting in growers searching for ways to maintain input costs at low levels. Inexpensive pesticides provide growers with the tools necessary to maintain profitability.

Crop scouting

- Crop scouting is expected to increase slowly but steadily. Passage of the Farm Security and Rural Investment Act of 2002 is expected to provide incentives for farmers and landlords to adopt practices such as crop scouting. Farms that adopt professional crop scouting services are not likely to see immediate reductions in pesticide use, but rather are expected to benefit by having higher yields and lower pesticide expense as pests are managed more effectively in the long run. Many tenant farmers have been reluctant to make such an investment in the past because crop scouting is seen as an outlay of cash without an immediate return.

Pest resistance

- The number and severity of pests that have resistance to some pesticides will grow. This is a result of the repeated use of products that contain similar modes of action and the failure of many growers to observe recommended procedures for avoiding pest resistance. As new instances of pest resistance occur there is a continuing need for a broad array of pesticides with different modes of action, even if many of these chemicals are restricted to an emergency-use-only basis. The discovery of corn rootworms with extended diapause, although not strictly a pest resistance issue, and also corn rootworms that prefer to lay eggs in non-corn crop fields, are likely to affect pesticide use habits. Although the actual presence of rootworms with extended diapause in a corn field is expected to require insecticide use, the fear of having or getting the pest may cause additional insecticide use, much of which may be unwarranted.

Professional pest management and pesticide application services

- More growers are relying on commercial dealers and applicators to select and apply herbicides. Along with this trend comes the knowledge, skill, and latest technological techniques for accurate and effective application of pesticides. The number of corn acres managed by independent crop consultants and farm management services are increasing. The Certified Crop Advisor program, and the potential for their designation as third-party vendors, presents a unique opportunity for a significant increase in the use of professional pest management services.

The Biologic and Economic Importance of Pests in Field Corn

- A somewhat quantitative measure of pest severity and impact can be found in Appendices E through H. Appendix E, F, and G provide an ordinal ranking of pests as determined through one of three separate means during the mid 1990's; a survey of scientists, a survey of growers, and an evaluation of the occurrence of pests (weeds only) from crop scouting records. These methods are admittedly based on perception of the problem more than their actual impact.
- Appendix H provides an overview of losses caused by weeds, insects, and plant diseases as estimated by University discipline specialists. This information was collected in 1997 through interviews of specialists throughout the Corn Belt who were familiar with corn production. Though the data are also biased by the perceptions of individuals, the estimates are tempered by research experience and constant interaction with colleagues who have carefully studied each pest. At the beginning of each interview each specialist was asked to provide estimates for the pests thought most significant to corn production within each state. Because the term 'significant' is quite subjective, fewer pests were mentioned by some state specialists than others. Hence, these figures should be construed to be conservative in their estimates of losses as they do not thoroughly cover many "less important" pests.
- The table in Appendix H presents the percent of acreage treated for each pest, the percent of acreage that remained above a threshold level after treatment, and the amount of loss resulting from treatment failure or lack of controls. Please note that the estimated losses include only the yield or quality reduction and do not include the cost of controls applied, whether the pest was controlled or not.
- Losses for the pest categories of weeds, insects and diseases ranged from $17 to $23 per acre with losses due to weeds lowest and losses due to plant diseases the highest. Losses due to insects averaged about $20 per acre for the Corn Belt. The overall message conveyed by the specialists was that the more visible the pest, the greater likelihood of its treatment and a resultant reduction in its impact. For example, plant pathologists often indicated that producers may be unaware of many serious diseases or at least unable to respond in time to effectively control or manage them. Hence, their estimate of crop loss was very significant for some less visible diseases. Adding these losses suggests that producers still lose approximately $60 per acre per year due to the effects of pests in field corn.
- The additional costs of control, to include improved seed, tillage, pesticides, and application costs can quickly increase these loss figures. Outside of the cost for improved seed, the cost of fungicide is minimal, probably less than one dollar per acre in most years. Cost of insecticides where used, can average $12 to $16 per acre. Current estimates suggest that insecticides may be used on about one third of the corn acreage in the Corn Belt, giving an average cost of from $4 to $6 dollars per acre of corn grown. This does not factor in the technology costs of improved Bt seed, where used. The cost for herbicides regularly exceeds $20 per acre and, since nearly all corn acres are treated with a herbicide, this figure is nominal for every acre. To these figures can be added the costs of pesticide application ($6 to $7 per acre) and the cost of tillage ($12-$20 per acre). These costs result in an average expenditure for pest management practices exceeding $50 for every acre of corn produced. Adding this cost to the estimate of losses for pests as indicated in the paragraph above, results in a very significant $110 per acre annual pest management expense, or roughly 8 billion dollars per year for the Corn Belt.
- The following sections of this document cover the pests that are most problematic for field corn production in the Corn Belt as determined by the producers who participated in the Strategic Planning Workshops. At the beginning of each section is a brief overview of each pest category (insects, weeds, diseases) and some of the challenges faced by producers using chemical or non-chemical control strategies. Material that follows presents background information on the pest or pest group, some information relative to its importance as a pest to field corn, and some of the factors that affect its severity. Pesticides and non-chemical controls that are available for a pest are listed, along with any limitations or other restrictions that may affect proper or necessary control of the pest.

Management of Key Insects in Field Corn

- The use of conservation tillage practices, which leaves crop residue on the soil surface and reduces or eliminates the use of tillage, provides a protective environment for soil inhabiting insects, and may result in greater insect injury to the corn crop than does conventional tillage practices. It is also true that weeds and grasses present in no-till fields prior to planting are attractive egg laying sites for black cutworms which, when the larvae hatch, will move onto the corn. Although many predatory and beneficial insects are also favored by conservation tillage, the increase in such practices is in part responsible for some increases in the severity of some insect problems.
- The severity of wireworms and white grubs is also tied to tillage practices and field cleanliness. No-till fields and fields that are excessively weedy are environments which foster the development of these insects. In general, regular herbicide use has improved field cleanliness, and weedy environments which promote white grub and wireworm activity are becoming very localized.
- Very dry or drought conditions may reduce the impact of some insects while others may flourish. Spider mites are particularly problematic when dry weather is sustained. Under such conditions these pests are less likely to be held in check by natural diseases or predators and may cause severe crop injury. Grasshoppers and chinch bugs are often more common in drought years.
- Whether insect control measures are used, and which treatments are selected, depends greatly on the economics of corn production. Low corn prices, production systems with lower yield potential (e.g. rainfed corn in western Corn Belt regions), 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 often 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 select for resistance in insect populations. The wide range of management options available to producers has permitted them to minimize the development of insect resistance. However, the recent appearance of corn rootworms that have developed methods of circumventing the cultural practices that have traditionally been used for their control (crop rotation), is a cause for much concern. More effort is needed 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 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 field corn 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.

Germination and emergence

1. Seedcorn maggot (*Delia platura*)

Biology and Life Cycle:

- The seedcorn maggot is the larva of a small fly. The flies are attracted to fields where relatively fresh animal manure, green manure and other organic material are 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.

Pest Distribution and Importance:

- Overall, seedcorn maggots are considered a minor pest in corn production.
- This pest tends to be 'spotty' in an infested field.
- Growers may be controlling seedcorn maggot with soil insecticides applied for rootworm, wireworms, etc.

Chemical controls:

Organophosphate + Organochlorine

Llindane+diazinon (Kernel Guard, Agrox, others) as a seed box treatment

- ★ Level of control - good to excellent
- ★ Must be added to planter box - exposure is a concern, allergies to dust - personal protective equipment is important
- ★ Odor is a concern, dust formulation is often mixed by hand with seed
- ★ Formulation is hard to work with, application may not be uniform, sticks to monitor sensors on planters giving false information and resulting in incorrect planting
- ★ Cheap insurance policy, cost effective
- ★ Lindane can be phytotoxic, (reduced germination)
- ★ Few environmental concerns
- ★ REI-PHI= Not applicable to seed treatments

Organophosphate

Terbufos (Counter) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control =Good
- ★ Long life in soil - systemic
- ★ Cost effective
- ★ Reduced worker exposure with Lock N Load
- ★ Possible reduced rate use for insect control
- ★ Use restrictions with some herbicides
- ★ Length of control sometimes unpredictable
- ★ Concern of possible contamination of water supplies
- ★ REI-48hrs PHI=NA
- ★ Unpleasant to work with - more toxic (environmental and human) than other controls

Chlorethoxyfos (Fortress) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control = Good to excellent
- ★ 5G formulation applied with Smartbox, reduces worker exposure
- ★ Smartbox pulsation causes erratic application of product
- ★ REI-NA for soil treatment PHI= NA

Organophosphate + pyrethroid

Tebupirimphos+cyfluthrin (Aztec) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control=Good to Excellent
- ★ Formulation is easy to work with
- ★ Good longevity
- ★ Smart Box reduces worker exposure (only 4.67G formulation)
- ★ Cutworm activity may influence choice for seedcorn maggot
- ★ Possible reduced rate usage
- ★ REI-48hrs PHI=NA for soil treatment

Carbamates

Carbofuran (Furadan) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control =Fair to Good, performance not always consistent
- ★ Only liquid formulation now used
- ★ Quite toxic -worker exposure concern - fields need to be posted for WPS
- ★ REI- NA for soil treatment PHI= NA

Pyrethriods

Tefluthrin (Force ST) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control=Good
- ★ Seed comes pre-treated
- ★ Reduced active ingredient per acre compared to granular formulation
- ★ Used for resistance management
- ★ REI- NA for seed treatment PHI= NA for seed treatment
- ★ Less toxic than some alternatives but may cause skin sensitivity

Bifenthrin (Capture)

- ★ Level of Control= Good

Tefluthrin (Force 3G) (Western region provided no additional comments for this pest/pesticide.)

- ★ Level of control =Good - Reliable performance in the field
- ★ Used for resistance management
- ★ Less toxic than some OP alternatives but may cause skin sensitivity
- ★ Possible reduced rate for insect control

Permethrin (Kernel Guard Supreme) (Western region provided no additional comments for this pest/pesticide.)

- ★ Newer formulation is not as dusty as old Kernel Guard

Phenylpyrazole

Fipronil (Regent)

- ★ Level of Control =Good

Neonicotinoids

Imidacloprid (Gaucho, Gaucho Extra, and Prescribe)

- ★ Level of control: Good to excellent
- ★ Seed with Gaucho pre-treated can be ordered; therefore, less worker exposure
- ★ Expense is a concern when selecting options, more expensive than planter box treatments
- ★ Systemic activity
- ★ Environmentally safer than most other options

Other Pest Management aids:

- ★ Later planting may accelerate crop growth and help avoid damage but is usually not a practical solution.
- ★ Field sanitation techniques, such as clean tillage may help to reduce insect damage, but is usually not a practical solution.

Pipeline Pest Management Tools:

★ Other neonicotinoids are under development

"To do" List

Regulatory needs

East: Regulatory: expedite registration of new compounds for soil insects when they become available

Research needs

East: Perform efficacy tests on new products for seedcorn maggot

East: Determine opportunities for predictive detection of damaging levels of seedcorn maggot

East:West: Continue trials on effectiveness of insecticides on seedcorn maggot looking particularly at minimum rates that still control maggots

West: Investigate new seed treatment formulations for ease of handling

West: Research cultural practices, crop residue, and how they affect maggots.

West: Research soil insects as a complex and look for overall thresholds.

Educational needs

East:West: Educate growers on safe use and Personal Protective Equipment (PPE) requirement of existing and new products for seedcorn maggot as they become available

East: Educate growers on what products are most effective for seedcorn maggot control

West: Educate growers on thresholds and when treatment is needed

2. True white grub [*Phyllophaga* sp.], **wireworm** [*Melanotus* sp.], **Japanese beetle grub [Popillia japonica]**, **grape colaspis**, **Seed Corn Beetle**

Biology and Life Cycle:

- These insects attack the germinating corn seed 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.

Pest Distribution and Importance:

- These pests are of moderate importance to corn production, though they are becoming more prevalent.
- White grubs rank second to corn rootworm **in NW Iowa**.
- Wireworms are perceived by producers to be more of a problem **west of the Missouri River** whereas white grubs are more of a problem **east of the Missouri River**. Both could become more serious as cultural practices change.
- White grubs have historically been worse after sod and may be more of a problem where forages are included in rotation with corn (species dependent).
- White grubs tend to be more problematic in earlier planted corn and control is dependent on the number of grubs present.
- White grubs have a three year life cycle and are harder to control in the more mature stages (3^{rd} yr) year.
- Annual white grubs rarely cause economic damage to corn

Chemical controls:

Organophosphate

Terbufos (Counter) (**Western region** provided no additional comments for this pesticide.)

★ Applied to furrow or band

★ Level of control =Good

★ Long life in soil -systemic

★ Considered cost effective

★ Possible reduced rate use for insect control

★ Under cool, moist conditions and high pH may break down quickly

★ Dry conditions tend to reduce control

- ★ Use restrictions with some ALS herbicides
- ★ Unpleasant to work with due to smell
- ★ Concern of possible contamination of water supplies
- ★ REI-48-72hrs PHI=NA
- ★ Reduced worker exposure with Lock N Load
- ★ More toxic (environmental and human) than other controls

Chlorethoxyfos (Fortress) (**Western region** provided no additional comments for this pesticide.)

- ★ Level of control=Good
- ★ 5G formulation with Smartbox reduces worker exposure
- ★ Smartbox pulsation causes erratic application of product
- ★ REI -48-72hrs PHI= NA

Chlorpyrifos (Lorsban) (**Eastern region** provided no additional comments for this pesticide)

- ★ Have to use high rates for grubs

Organophosphate + Organochlorine

Lindane+diazinon (Kernel Guard)

- ★ Seed box treatment
- ★ **East:** Level of control - good to excellent
- ★ **West:** Level of control (Grubs) - Suppression of light infestation only
- ★ **West:** Level of control (Wireworms) -Good
- ★ 10-20% of corn acreage is treated where there is a history of problems
- ★ Add to planter box - exposure is a concern, allergies to dust
- ★ REI- NA PHI-NA

Pyrethriods

Permethrin (Kernel Guard Supreme) (**Western region** provided no additional comments for this pesticide.)

- ★ Newer formulation is not as dusty
- ★ Only control wireworms
- ★ REI- NA PHI-NA

Tefluthrin (Force 3G)

- ★ Level of control =Good, performance considered reliable in trials and field
- ★ **West:** half rates are perceived as sufficient for wireworm control
- ★ REI- 0hrs PHI-NA
- ★ Less toxic than some alternatives
- ★ Possible reduced rate use for insect control
- ★ Risk of skin sensitivity may influence decision to use product

Bifenthrin (Capture) (**Western region** provided no additional comments for this pest/pesticide.)

- ★ Level of control= Fair to good (though data is sparse)
- ★ Has residual soil activity
- ★ REI- 24hrs PHI= 30d

Neonicotinoids

Imidacloprid (Gaucho, Gaucho Extra, and Prescribe)

- ★ Level of control= perceived excellent by producers (empirical data may suggest less control)
- ★ Seed with Gaucho is pretreated, therefore less worker exposure
- ★ REI- NA PHI-NA

Other Pest Management aids:

- ★ Good grass weed control reduces wireworm problems
- ★ Field sanitation has little effect for these insects

Pipeline Pest Management Tools:

- ★ Neonicotinoids - still in research phase
- ★ Cruiser (thiamethoxam) as seed treatment

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of insecticides towards secondary soil pests - white grubs
East: Determine relationship between planting date, temperature and infestations of white grubs
East: Research economical control of Japanese beetle grubs (MI, IN, IL)
East:West: Determine opportunities for predictive detection of damaging levels of white grubs and wireworms
West: Determine the efficacy of tillage on white grubs
West: Research to understand dynamics of white grub populations in corn/soy rotations
West: Determine if summer fallow impacts white grub populations
West: Research long term effect of use/disuse of soil insecticides on white grub and wireworm populations
Eastd:West: Evaluate better sampling methods for white grub

Extension needs

East:West: educate growers on how to use current and new products for white grubs as information becomes available
West: Update publications on white grubs and wireworms with the focus on how these pests are now moving from being a problem only in sod situations to causing problems in current rotations (e.g. corn-soybean rotations).

Vegetative stages

3. Corn rootworm (western [Diabrotica virgifera virgifera] and northern [D. Barberi])

Biology and Life Cycle:

- Adults lay eggs in late summer and early fall which 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 many farmers.
- Some populations of NCR 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 corn-soybean rotation can fail. This is currently occurring **in parts of Minnesota, Iowa, South Dakota, Illinois, Indiana, (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 WCR 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 WCR soil-applied insecticide treatments are generally a standard practice in corn acreage following corn and non-corn crops that target the larvae.

Pest Distribution and Importance:

- This pest has significant importance to corn production.
- Rootworm transgenic hybrids may become available in 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.
- Rootworm insecticides are applied in furrow or in bands. Rootworms survive in the untreated areas, therefore allowing part of the field to remain untreated has relieved the resistance problems. Foliar broadcast applications targeted against adult rootworms have been used in the western Corn Belt in addition to in-furrow or band applications.

Chemical treatments: (Soil-applied insecticides for larval control)

Organophosphates

Terbufos (Counter 15G) @ 8 ounces per 1,000 ft. of row.
Terbufos (Counter CR) @ 6 ounces per 1,000 ft. of row

★ Level of control = good, most consistent performance in trials
★ Dry conditions tend to reduce control

- ★ More toxic (environmental and human) than other controls
- ★ Restrictions with some ALS herbicide use due to interactions
- ★ Possible reduced rate use for insect control
- ★ REI-48-72hrs PHI= NA

Chlorpyrifos (Lorsban 15G) @ 8 ounces per 1,000 ft. of row
- ★ Level of control = moderate but erratic
- ★ Perceived as safer to handle than terbufos
- ★ Does not have herbicide restrictions
- ★ Producers perceive activity on cutworm an advantage for rootworm control
- ★ REI- 24hrs PHI= 35d

Phorate (Thimet 20G) @ 6 ounces per 1,000 ft. of row.
- ★ Level of control = perceived by producers as poor & considerably erratic (may not be supported by empirical data)
- ★ Not much used because of low level of control
- ★ Considered inexpensive relative to many other insecticides
- ★ Some states recommend not to use if planting before May 1
- ★ For banded applications only
- ★ **West:** used more at cultivation
- ★ Also some restrictions on use of herbicides following phorate
- ★ REI- 48-72hrs PHI= 30d

Chlorethoxyphos (Fortress 5G) @3.25 ounces per 1,000 ft. Of row in 30 inch -row spacings
- ★ Level of control = Perceived by producers as poor to fair & erratic (may not be supported by empirical data)
- ★ Very volatile, Illinois restricts to in-furrow application
- ★ Not used much
- ★ REI- 48-72hrs PHI= NA

Pyrethoid + neonicotinoid (Prescribe seed treatment) (**Eastern region** had no comment for this pesticide)
- ★ Level of control=not recommended for high populations of rootworms
- ★ Has activity against seedling insects that may influence selection for rootworm
- ★ Convenience of seed treatment may influence selection of product
- ★ Systemic activity against flea beetles (maybe cutworms) that may influence selection of product
- ★ REI-NA PHI-NA

Organophosphate + Pyrethroid

Tebupirimphos+cyfluthrin (Aztec 2.1G) @ 6.7 ounces per 1,000 ft. of row.
- ★ Level of control = good to excellent
- ★ Option is available to use in SmartBox system with 4.67G formulation
- ★ Activity on cutworm may influence selection for rootworm
- ★ Possible reduced rate usage (Iowa using at half rate in trials w/ comparable control)
- ★ REI- 48-72hrs PHI= NA
- ★ **West:** longer residual activity than Counter

Pyrethroid

Tefluthrin (Force 1.5G) @ 8 ounces per 1,000 ft. of row
Teflutrhin (Force 3G) @ 4 ounces per 1,000 ft. of row
- ★ Level of control = good to excellent
- ★ Performance perceived in trials and field as steady
- ★ Cutworm activity may influence selection for rootworm control
- ★ Perceived as less toxic than OPs but can cause some irritation to skin
- ★ Possible reduced rate use for insect control
- ★ REI-0hrs PHI= NA

Bifenthrin (Capture 2E) 0.30 fl oz per 1,000 ft of row.
- ★ Level of control = producers perceived control as fair to good though experience with product is limited

- ★ Liquid formulation
- ★ REI-24hrs PHI= 30d
- ★ **West:** ability to be mixed with fertilizer affects decision to use
- ★ Applied at planting
- ★ **West:** has activity against other seed/seedling pests
- ★ **West:** dry conditions limit efficacy
- ★ **West:** human exposure is reduced and field operations more timely

Carbamate

Carbofuran (Furadan 4F) @ 2 pints per acre – broadcast post- (at cultivation)

- ★ Level of control = Fair to poor with control perceived as inconsistent
- ★ Very limited use; pesticide of last resort or rescue treatment only, has been removed from at-planting recommendations
- ★ REI-2-14d PHI= 30d
- ★ Applicator exposure risk is perceived as high
- ★ **West:** timing is critical

Phenylpyrazole

Fipronil (Regent 4SC) @4.2 fl oz/acre for 30 inch row spacings

- ★ Level of control = producers perceive control as good (empirical data suggests that control is fair at best and inconsistent)
- ★ Liquid formulation
- ★ Some producers use in place of planter box treatments
- ★ REI-24hrs PHI= 90d
- ★ **West:** dry conditions (which can limit efficacy) will affect decision to use product
- ★ **West:** can be mixed with fertilizer at plant which reduces human exposure and improves timeliness of planting.

Other pest management aids:

- ★ Change in tillage or sanitation; not effective for this pest.
- ★ Monitoring systems - whole plant-beetle counts in continuous corn, sticky traps in soybean fields to base treatment decisions in following season.

Pipeline pest management tools:

- ★ **East:West:** Potentially BT corn hybrids? Monsanto and Pioneer are both working on GMO's. May be multiple events to help control rootworm larvae.
- ★ **East:West:** Other neonicotinoids also being developed for seed treatments

"To do" List

Research needs

East: Research is needed on CRW resistance to crop rotation (eastern Corn Belt) and insecticides (western Corn Belt - foliar broadcast treatments)

East: Research efficacy trials for control of corn rootworm larvae

West: Research expression of traits in grain versus plant, if no expression in grain it would likely reduce barriers to trade

West: Research prevalence of extended diapause

West: Research use of reduced rates on rootworm larvae

West: Research expansion of area of extended diapause CRW biotypes

West: Research use of diagnostic tools to determine yield loss from root damage

Regulatory needs

West: Research is needed to develop resistance management plans for GMOs since beetles can fly/travel long distances.

West: Research export and domestic market approval for GMOs- what happens if there is no European or Japanese approval?

West: Research methods of maintaining grain separation for agronomic traits in light of cross pollination issues

Education needs

East:West: Educate growers on monitoring systems in soybean prior to planting corn
East: Educate growers through demonstrations and incentives for trap utilization
West: Educate public on benefits of GMO crops (less toxic to humans)

(Chemical treatments for adult beetles)
In the eastern Corn Belt, in areas of continuous corn; growers are encouraged to rotate crops.
In the western Corn Belt treatment for adult beetles primarily occurs to prevent economic egg laying.

Organophosphate

Chlorpyrifos (Lorsban 4E) @ 1 to 2 pints per acre
- ★ Level of control =fair
- ★ REI-24hrs PHI= 353d

Methyl Parathion (Penncap-M) @ 1 to 2 pints per acre
- ★ Level of control=excellent
- ★ Encapsulated formulation that can be hazardous to bees
- ★ Adult resistance documented in western Corn Belt
- ★ REI-48hrs PHI= 14d

Carbamates

Carbaryl (Sevin XLR) @ 2 to 4 pints per acre,
Carbaryl (Sevin 80W SP) @ 1.25 to 2.5 pounds per acre
- ★ Level of control=good to excellent
- ★ Classified a hazard to bees
- ★ Adult resistance documented in western Corn Belt
- ★ REI-12hrs PHI= 1d

Pyrethroids

Permethrin (Ambush 2EC)@ 6.4 to 12.8 ounces per acre
Permethrin (Pounce 3.2EC)@ 4 to 8 ounces per acre
- ★ Level of control= fair
- ★ REI-12hrs PHI= 30d

Esfenvalerate (Asana XL) 0.66 EC @ 5.8 to 9.6 ounces per acre
- ★ Level of control=fair
- ★ REI-12hrs PHI= 21d

Bifenthrin (Capture) (**Western region** provided no additional comments for this pesticide.)
- ★ Control= Perceived as good to excellent but not yet known whether performance is consistent across Corn Belt
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ May kill beneficials
- ★ REI-24hrs PHI= 30d

Lambda-cyhalothrin (Warrior 1E) @ 1.92 to 3.2 fluid ounces per acre
- ★ Level of control=good
- ★ REI- 24hrs PHI= 21d

Pipeline pest management tools:
- ★ BT corn for rootworm management

Other pest management aids:
- ★ Crop rotation still works well in most areas
- ★ Crop rotation highly effective in many areas

"To do" List

Regulatory needs

None indicated

Research needs

East: Research to develop beetle thresholds with traps in soybean to determine if beetle treatments are necessary

East: Research low-dose compounds, as well as low-dose insecticide baits for adult beetle control

Education needs

East: Educate growers on monitoring systems in soybean if research outcome is feasible

East: Educate growers on use demonstrations and incentives for trap utilization

4. European corn borer [*Ostrinia nubilalis* (Hubner)]

Biology and Life Cycle:

- Corn borers overwinter as larvae in corn stalks and pupate in the spring. Moths emerge from these pupae in May and June, the adults mate and females place eggs on the underside of corn leaves and on other suitable plant species. A second generation occurs in late July-August. In the northern Corn Belt only one generation may occur (univoltine populations).
- The moths prefer the tallest corn 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.
- Ear droppage is a problem and stalk tunneling can predispose plant to stalk rots. Economic thresholds for second generation corn borer are difficult to determine because of the long time period of egg laying an the relatively short persistence of foliar insecticides.

Pest Distribution and Importance:

- This pest is of significant importance to corn production but is quite variable from year to year.
- Bt products have helped with control but refuge areas need other pesticides for effective control. Insect resistance management plans are mandated by law. Bt corn adoption is 10-20% in **most eastern Corn Belt states** and is above 30% adoption **in Minnesota**. Adoption also depends on previous year insect populations.
- 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, multiple sprays are sometimes needed, and growers are unsure if the cost of chemicals will be returned. 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 of first generation than liquid forms. For rescue treatment of 2nd 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).
- Some corn varieties have a natural tolerance to this insect.
- Areas where both univoltine and bivoltine corn borers occur presents a problem (i.e. continuous emergence of new adults provides no clear cut generations to target with insecticides.)

Chemical treatments:

Organophosphates

Chlorpyrifos (Lorsban 15G) @ 5 to 6.5 pounds per acre

★ **East:** Level of control =fair to good for 1st generation
★ **West:** Level of control =excellent if timed right
★ REI-24hrs PHI= 35d
★ **West:** Liquid formulation applied by irrigation, chemigation, and aerially.
★ **West:** Some applied by ground for first generation

Chlropyrifos (Lorsban 4E) @ 1Qt/acre

★ Level of control=fair
★ **West:** May be applied by chemigation

- ★ REI-24hrs PHI= 35d

Methyl Parathion (Penncap-M) @ 1 to 2 pints per acre
- ★ Level of control =not indicated
- ★ **West:** High potential for mite flares
- ★ **West:** Toxic to honey bees if applied during pollination
- ★ REI-48hrs PHI= 14-21d

Biologicals

<u>Bacillus thuringiensis</u> (several trade names) See individual labels for rates.
- ★ Level of control =good
- ★ **West:** No mite flare
- ★ **West**: May be applied by chemigation
- ★ REI-4hrs PHI= 0d

Spinosad (Tracer)
- ★ Level of Control=Fair
- ★ REI-4hrs PHI-28d

Carbamates

Carbofuran (Furadan 4F) @ 0.25 to 0.5 pints per acre
- ★ **West:** Level of control=Good
- ★ **West:** Seldom used due to toxicity and applicator safety concerns
- ★ REI-2-14d PHI=30d

Pyrethroids
- ★ Less hazardous than other compound families
- ★ Skin irritation to applicators

Permethrin (Ambush 2EC) @ 6.4 to 12.8 ounces per acre
Permethrin (Pounce 1.5G) @ 6.7 to 13.3 ounces per acre
Permethrin (Pounce 3.2EC) @ 4 to 8 ounces per acre
- ★ Level of control =highly effective
- ★ REI-12hrs PHI= 30d
- ★ **West:** Granular is used for first generation as it goes into the whorl better and liquid is used for 2nd generation.
- ★ **West**: Potential for mite flaring

Esfenvalerate (Asana XL) 0.66 EC @ 5.8 to 9.6 ounces per acre
- ★ **West:** Level of control = less effective than other pyrethroids for second generation
- ★ REI-12hrs PHI= 21d

Lambda-cyhalothrin (Warrior) @ 2.56 to 3.84 fluid ounces per acre
- ★ **West:** Level of control=highly effective
- ★ REI-24hrs PHI= 21d

Bifenthrin (Capture 2EC) 2.1-6.4 fl oz per acre
- ★ **West:** Level of control=highly effective
- ★ **East**: Inconsistent performance to date, only on market a few years with limited experience
- ★ Liquid formulation
- ★ **West:** mite control (requires higher rates) may affect decision to use for corn borer
- ★ REI-24hrs PHI= 30d

Phenylpyrazole (Western region provided no additional comments for this pest/pesticide.)

Fipronil (Regent 4SC) @4.2 fl oz/acre for 30 inch row spacings
- ★ Level of control =50-70% control of 1st generation
- ★ Liquid formulation
- ★ Marketed to provide some 1st generation ECB control
- ★ REI-24hrs PHI= 90d

Pipeline pest management tools*:*
- ★ None indicated

Other pest management aids:
- ★ Early harvest o crop may be possible where ECB is present to preserve yields and quality.

★ GMO (Bt) hybrids

★ Shredding stalks/tillage reduces overwinter survival but not used for soil considerations

"To do" List

Regulatory needs

West: Need more concrete regulations on use of refuges, including grower oversight, and issues with stacked traits.

Research needs

East: Research insecticide efficacy towards ECB 1st and 2nd brood generations

East: Research low-dose compounds for control of ECB 1st and 2nd brood generations

West: Research halo/border effect of putting BT on outside of field

West: Research non-BT varieties that are resistant to ECB

West: Research predictive models based on last years populations and winter conditions

Education needs

East: Educate growers on how to use new products for ECB as they become available

East: Educate growers on what products are most effective for ECB control

East: Educate growers on use of existing models for threshold determination

5. Southwestern Corn Borer (*Diatraea grandiosella*)

Biology and Life Cycle:

- Its life history and seasonal occurrence are similar to ECB. The second generation egg laying usually coincides with silking stage corn. Eggs are laid on both the upper and lower leaf surfaces.
- Heavy second generation infestations can develop even in areas where first generation activity was light.
- 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.

Pest Distribution and Importance:

- SWCB usually causes only light damage to early planted corn
- In late corn plantings, first generation larvae can tunnel deep enough to kill the growing point and cause "dead heart"
- SWCB is not controlled by DIMBOA based plant resistance which protects small plants from ECB feeding
- Treatment for second generation SWCB is generally applied when 20 to 25% of the plants are infested with eggs. Often a second application 7 to 10 days after the first is needed if significant egg laying occurs after the first application.
- In BT corn, the same hybrids that have good ECB resistance are also resistant to SWCB
- When considering chemical control of second generation SWCB, consider presence of spider mites in making product selection.
- In the **eastern and 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) attacking field corn. In these areas, economic losses attributed to SWCB is more frequent.

Chemical Controls (Eastern region provided no additional comments for this pest/pesticide.)

Carbamates

Carbofuran (Furadan 4F)

★ Level of Control= fair

★ REI-2-14d PHI-30d

★ Two applications 14 days apart are required

Pyrethroids

Permethrin (Ambush 2E)

(Pounce 3.2E)

- ★ Level of control= fair
- ★ REI-12hrs PHI= 30d
- ★ 0.15 lb/acre Pounce or higher rates needed for SWCB control

Esfenvalerate (Asana XL)

- ★ Level of Control= fair
- ★ REI-12hrs PHI= 21d
- ★ Two or more applications may be necessary to give control, especially if egg laying is prolonged. Higher rates are recommended for moderate to heavy populations.

Bifenthrin (Capture 2EC)

- ★ Level of Control= fair
- ★ Avoid rates below 0.08 lb ai/acre in areas where Capture is considered essential for spider mite control.
- ★ REI-24hrs PHI= 30d

Biologicals

Bacillus thuringiensis (several trade names) See individual labels for rates.

- ★ Level of control =not indicated
- ★ **West:** No mite flare
- ★ REI-4hrs PHI= 0d

Spinosad (Tracer)

- ★ Level of Control=Fair
- ★ REI-4hrs PHI- 28d

Other pest management aids:

- ★ Early planting tends to enable a plant to tolerate damage but does not result in reduced infestation levels
- ★ Use Bt hybrids to reduce losses from SWCB
- ★ Avoid late-planted corn; extremely late planted corn may be heavily infested with SWCB, and yield losses due to tunneling may be extensive
- ★ Where soil erosion is not a concern, deep, clean plowing of corn stubble to a depth of 5 or more inches will bury larvae and pupae and prevent a high percentage of moth emergence the next spring
- ★ In non-BT corn, early harvest of heavily infested fields before girdled plants start falling is very important. In southern KS, corn needs to be harvested in early October
- ★ Overwinter survival of SWCB is highest where corn stubble is left undisturbed. No-till producers need to be aware of the increased risk. Fall tillage to break up root stubble and expose borers to natural enemies and winter environment can decrease borer survival.

"To Do" List

None Indicated from either region.

6. Black cutworm [*Agrotis ipsilon* Hufnagel], Other cutworm species include: bristly, bronzed, claybacked, dingy, glassy, redbacked, sandhill, spotted, and variegated cutworms.

Biology and Life Cycle:

- A number of cutworm species cause stand losses to young corn 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 prefer weedy areas and plant residue to lay eggs.
- Other cutworm species do overwinter in the Midwest, survival varies with winter weather.

Pest Distribution and Importance:

- 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 portion of the region**, and should be considered a pest of significant importance.
- Biotech Bt corn for cutworm is available in some hybrids
- Scouting is recommended and thresholds have been developed.
- After the V6 stage corn is tolerant.

Chemical treatments:

Organophosphate

Chlorpyrifos (Lorsban 15G) @ 5 to 6.5 pounds per acre
Chlorpyrifos (Lorsban 4E) @ 1 to 2 pts per acre

- ★ Level of control = fair to good
- ★ 15G is T-banded application
- ★ Planting time application, preventative only
- ★ **West:** Considered cost effective by producers
- ★ 15G formulation is not a Restricted Use Pesticide
- ★ REI-24hrs PHI= 35d

Methyl-Parathion (Penncap-M) (Eastern region provided no additional comments for this pesticide.)

- ★ Level of control= fair
- ★ Aerially applied only and very little is used (Not recommended by most states)
- ★ Can be a low cost option
- ★ Applicator and worker safety issues with ground application
- ★ Toxic to bees
- ★ REI-48hrs PHI-14-21d

Chlorethoxyphos (Fortress 5G) @3.25 ounces per 1,000 ft. Of row in 30 inch -row spacings

- ★ Only used in SmartBox application -no human exposure (new formulation 2.5G cannot be used in SmartBox)
- ★ Level of control = Fair
- ★ Not used much
- ★ REI-48-72hrs PHI= NA

Pyrethroids

Permethrin (Ambush 2EC) @ 6.4 to 12.8 ounces per acre
Permethrin (Pounce 1.5G) @ 8 ounces per 1000 feet of row
Permethrin (Pounce 3.2EC) @ 4 to 8 ounces per acre

- ★ **East:** Level of control = good
- ★ **West:** Level of control = excellent
- ★ Widely used
- ★ REI-12hrs PHI= 30d

Esfenvalerate (Asana XL) 0.66 EC @ 5.8 to 9.6 ounces per acre,

- ★ Level of control = good
- ★ REI-12hrs PHI= 21d

Lambda-cyhalothrin (Warrior) @ 1.92 to 3.2 fluid ounces

- ★ **West:** Level of control = good to excellent
- ★ **West:** Offers widest spectrum of activity for an insecticide
- ★ REI-24hrs PHI= 21d

Bifenthrin (Capture)

- ★ Control= Perceived as good to excellent but not yet known whether performance is consistent across Corn Belt
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ May kill beneficials
- ★ REI-24hrs PHI= 30d

Tefluthrin (Force ST)

- ★ Level of control=Fair
- ★ REI-0hrs PHI= NA

- ★ Less toxic than some alternatives but may cause skin sensitivity

Biological (**Eastern region** provided no comments for this pesticide.)

Bacillus thuringiensis (many)

- ★ Level of control =Very little used because control is so variable
- ★ Timing is critical
- ★ Other products more cost effective
- ★ REI-4hrs PHI= 0d

Pipeline pest management tools:

- ★ Transgenic Bt corn hybrids

Other pest management aids:

- ★ Tillage applied at least two weeks before planting greatly reduces damage by black cutworms.
- ★ Improved Bt hybrids may provide good control

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of existing insecticides towards black cutworm larvae

East: Research low-dose of existing compounds for control of black cutworm larvae

West: Research impact of new transgenic hybrids on cutworms

Education needs

East: Educate growers on how to use new products for black cutworm larvae as they become available

East: Educate growers on what products are most effective for black cutworm larval control

West: Educate growers on availability of existing forecasting models to help them know when to scout

7. Stalk borer [Papaipema nebris]

Biology and Life Cycle:

- Stalk borers are a native insect that damage corn 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 and broadleaf weeds, 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.

Pest Distribution and Importance:

- This pest has a moderate level of importance; but local outbreaks can have a significant impact on yields.

Chemical treatments:

Organophosphate

Chlorpyrifos (Lorsban 4E) @ 2 to 3 pints per acre

- ★ Level of control = fair
- ★ REI-24hrs PHI= 35d

Biological

None indicated

Pyrethroid

Permethrin (Ambush 2EC) @ 6.4 to 12.8 ounces per acre

Permethrin (Pounce 1.5G) @ 6.7 to 13.3 ounces per acre

Permethrin (Pounce 3.2EC) @ 4 to 8 ounces per acre

- ★ Level of control = good to excellent with proper timing of application

- ★ REI-12hrs PHI= 30d

Bifenthrin (Capture)

- ★ Control= Perceived as good to excellent but not yet known whether performance is consistent across Corn Belt
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ May kill beneficials
- ★ REI-24hrs PHI= 30d

Esfenvalerate (Asana XL) 0.66 EC @ 5.8 to 9.6 ounces per acre

- ★ Level of control= fair
- ★ REI-12hrs PHI= 21d

Lambda-cyhalothrin (Warrior) @ 2.56 to 3.84 fluid ounces per acre

- ★ Level of control= fair
- ★ REI-24hrs PHI= 21d

Pipeline pest management tools:

- ★ Improved Bt corn hybrids

Other pest management aids:

- ★ Clean tillage in the spring will destroy most overwintering eggs on weed residues in the field
- ★ Burn field edges and grassy borders in the spring reduces overwintering eggs
- ★ Adjusting planting dates has little or no effect on this pest
- ★ Some Bt corn hybrids may suppress populations

"To do" List

Regulatory needs

None indicated

Research needs

East: Research general insecticide efficacy towards stalk borer larvae

East: Research low-dose compounds for control of stalk borer larvae

Education needs

East: Educate growers on how to use new products for stalk borer larvae as they become available

East: Educate growers on what products are most effective for stalk borer larval control

8. Corn leaf aphids [*Rhopalosiphum maidis*]

Biology and Life Cycle:

- Corn leaf aphids are colonial sucking insects that can rapidly increase population numbers to cover the emerging tassels and youngest leaves of stage R1 corn 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, and seed corn producers must pay special attention to protect pollen availability from inbred lines.

Pest Distribution and Importance:

- Except under very dry conditions, this pest is of minor importance to corn production in most areas.
- This pest does not overwinter in most of the Corn Belt
- Where there are heavy Johnsongrass infestations are controlled, the aphid populations may move to nearby corn.
- Aphids also carry the Maize Dwarf Mosaic (MDMV) virus.

Chemical treatments:

Dimethoate (Cygon) @ 0.66 to 1 Pint per Acre

- ★ Level of Control = fair

- ★ REI-48hrs PHI= 14d

Chlorpyrifos (Lorsban 4E) @ 1 to 2 Pints per Acre

- ★ Level of Control = fair
- ★ REI-24hrs PHI= 35d

Methyl Parathion (Penncap-M) @ 2 to 3 Pints per Acre

- ★ Level of Control = fair
- ★ REI-48hrs PHI-14-21d

Pyrethroids

Bifenthrin (Capture)

- ★ Control= fair
- ★ May kill beneficials
- ★ REI-24hrs PHI= 30d

Lambda-cyhalothrin (Warrior) @ 2.56 to 3.84 fluid ounces per acre

- ★ Level of control =not indicated
- ★ REI-24hrs PHI= 21d
- ★ Not recommended in some states

Pipeline pest management tools:

- ★ None indicated

Other pest management aids:

- ★ None indicated

"To do" List

Regulatory needs

East: Research non-chemical means of keeping corn leaf aphids at low populations

Research needs

East: Research low-dose compounds for control of corn leaf aphids

Education needs

East: Educate growers on how to use new products for corn leaf aphids as they become available

East: Educate growers on what products are most effective for corn leaf aphid control

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

Western region: no comments were provided for this pest

Biology and Life Cycle:

- Corn flea beetles are small insects that feed on corn 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 is of special concern. If the 3-month sum of averages is below 95, the risk is relatively small.

Pest Distribution and Importance:

- Scout and apply rescue treatments should corn flea beetle numbers reach the economic threshold.
- Treatment is seldom used unless the producer can justify a broad spectrum insecticide to control other existing insects.
- This pest is considered of minor importance to field corn in most areas of the **eastern Corn Belt**. More important to seed corn production because of inbred susceptibility to Stewart's wilt, and higher productive value.

Chemical treatments:

Organophosphates not economical for just flea beetle control - but may provide some control of flea beetles when used for other insect pests

Chlorpyrifos (Lorsban 4E) @ 2 to 3 Pints per Acre

- ★ Level of Control = fair

- ★ REI-24hrs PHI= 35d

Methyl-parathion (Penncap-M) @ 2 to 3 Pints per Acre

- ★ Level of control = fair
- ★ REI-48hrs PHI-14-21d

Terbufos (Counter 15G) @ 8 ounces per 1,000 ft. of row

Terbufos (Counter CR) @ 6 ounces per 1,000 ft. of row

- ★ Level of control = fair
- ★ Dry conditions tend to reduce control
- ★ Restrictions with some herbicide use due to interactions
- ★ REI-48-72hrs PHI= NA

Phorate (Thimet 20G) @ 6 Ounces per 1,000 Ft. of Row

- ★ Level of Control = fair
- ★ Not much used
- ★ Inexpensive
- ★ Banded applications only
- ★ Some herbicide restrictions
- ★ REI-48-72hrs PHI= 30d

Carbamates

Carbofuran (Furadan 4F) @ 2.5 Fl Ounces per 1,000 Ft of Row

- ★ Level of control = fair
- ★ Not recommended in some states
- ★ REI-2-14d PHI

Carbaryl (Sevin XLR) @ 1 to 2 Quarts per Acre

- ★ Rescue treatment
- ★ Level of control = Good
- ★ REI-12hrs PHI= 1d

Pyrethroids

Permethrin (Ambush 2EC) @ 6.4 to 12.8 Ounces per Acre
(Pounce 3.2EC) @ 4 to 8 Ounces per Acre

- ★ Level of control = fair
- ★ REI-12hrs PHI= 30d

Esfenvalerate (Asana XL) 0.66 Ec @ 5.8 to 9.6 Fl Ounces per Acre

- ★ Level of control = fair
- ★ REI-12hrs PHI= 21d

Lambda-cyhalothrin (Warrior) @ 2.56 to 3.84 Fl Ounces per Acre

- ★ Level of Control = fair
- ★ REI-24hrs PHI= 21d

Bifenthrin (Capture 2EC) 2.1 - 6.4 Fl Ounces per Acre

- ★ Level of Control = fair
- ★ REI-24hrs PHI= 30d

Neonicotinoids

Imidacloprid (Gaucho or Prescribe)

- ★ Level of control = good
- ★ Can be used to control flea beetle through 5th leaf stage.
- ★ Seed pretreated with Gaucho and Prescribe can be ordered; therefore less worker exposure

Imidacloprid (Gaucho Xtra) (Seed Industry)

- ★ Can be used to control flea beetle to first true leaf stage.
- ★ REI-12hrs PHI-7d

Pipeline pest management tools:

- ★ Neonicotinoids

Other pest management aids:

- ★ Hybrids vary in tolerance to Stewart's wilt disease.

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of current insecticides towards corn flea beetles

Education needs

East: Educate growers on how to use new products for corn flea beetles as they become available

East: Educate growers on what products are most effective for corn flea beetle control

10. Sod webworm [*Crambus* sp]

Western region: no comments were provided for this pest.

Biology and Life Cycle:

- One generation per year occurs in the Midwest. Webworms that attack corn overwinter as partly grown caterpillars which developed in sod or other grasses the previous summer and fall. Larvae feed on leaves and may also cut the stalk like cutworms. Larvae are active as soon as corn emerges. Threshold levels for control are similar to corn cutworms.

Pest Distribution and Importance:

- This insect is an occasional pest of corn and treatments are rarely required.
- This is a minor pest to corn production, usually in fields of corn planted into grass sod.

Chemical treatments:

Organophosphates:

Chlorpyrifos (Lorsban)

★ Control = Fair

★ REI-24hrs PHI= 35d

Pyrethroids

Permethrin (Pounce 1.5G) @ 6.7 to 13.3 ounces per acre

Permethrin (Pounce 3.2EC) @ 4 to 8 ounces per acre

★ Level of control = good to excellent with proper timing of application

★ REI-12hrs PHI= 30d

Lambda-cyhalothrin (Warrior) @ 2.56 to 3.84 fluid ounces per acre

★ Level of control = fair

★ REI-24hrs PHI= 21d

Bifenthrin (Capture)

★ Control= fair

★ Can be applied through irrigation

★ Has good residual control

★ May kill beneficials

★ REI-24hrs PHI= 30d

Pipeline pest management tools:

None indicated

Other pest management aids:

★ Tillage of grass sod the year before corn production reduces populations since moths do not lay eggs in bare soil.

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of current insecticides towards webworms

Extension Needs

East: Educate growers on how to use new products for webworms as they become available

East: Educate growers on what products are most effective for webworm control

11. Hop vine borer (*Hydraecia immanis*)

Western region: No comments were provided for this pest.

Biology and Life Cycle:

- Hop vine borers are soil dwelling and bore into the base of young corn plants where they destroy the growing points.
- Localized infestations can be intense and are often associated with weedy fields

Pest Distribution and Importance:

- Very targeted regionally - very similar life cycle to stalk borer - more of a pest in the **northern latitudes**.
- Considered a minor corn production pest.
- Timing of controls must be exact.

Chemical treatments:

Pyrethroids

Permethrin (Pounce 3.2EC) @ 4 to 8 ounces per acre

- ★ Level of control =not indicated
- ★ REI-12hrs PHI= 30d

Pipeline pest management tools:

- ★ None indicated

Other pest management aids:

- ★ None indicated.

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of current insecticides towards hop vine borers

Education needs

East: Educate growers on how to use new products for hop vine borers as they become available

East: Educate growers on what products are most effective for hop vine borers control

12. Armyworm [*Pseudaletia unipuncta* Haworth]

Western region: No comments were provided for this pest.

Biology and Life Cycle:

- Armyworm damage is characterized by ragged feeding and large amounts of frass (fecal pellets) on plants. The most severe damage occurs in corn 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 army worm larvae feeding on the grass and the level of damage to corn.

Pest Distribution and Importance:

- Very sporadic, but when it appears, it can be a significant pest - capable of destroying entire fields.
- Armyworms often move from wheat fields to corn fields as the season progresses.
- Scouting and spraying of field perimeter is an effective method of control - no-till corn field near rye or other grassy field.
- Bt corn is effective in controlling armyworm infestations.
- This pest is considered of low to moderate importance to corn production.

Chemical treatments:

Organophosphate

Chlorpyrifos (Lorsban 4E) @ 1 to 2 pts/acre

- ★ Level of control = fair to good
- ★ REI-24hrs PHI= 35d

Methyl Parathion (Penncap-M) @ 2 to 3 pts/acre
- ★ Level of control = fair
- ★ REI-48hrs PHI-14-21d

Carbamates
Carbaryl (Sevin)
- ★ Control= fair
- ★ REI-12hrs PHI= 1d

Biological
Bacillus thuringiensis (several trade names)
- ★ Level of control = fair but will not work on larger larvae
- ★ REI-4hrs PHI= 0d

Spinosad (Tracer)
- ★ Control= Fair
- ★ REI-4hrs PHI- 28d

Carbamates
Methomyl (Lannate LV) @ 0.75 to 1.5 pints per acre
- ★ Level of control = fair
- ★ REI-48hrs PHI= 21d

Pyrethroids
Permethrin (Ambush 2EC) @ 6.4 to 12.8 ounces per acre –
(Pounce 1.5G) @ 6.7 to 13.3 ounces per acre
(Pounce 3.2EC) @ 4 to 8 ounces per acre – prior to brown silk stage
- ★ Level of control= fair to good
- ★ REI-12hrs PHI= 30d

Esfenvalerate (Asana XL) 0.66 EC @ 5.8 to 9.6 ounces per acre
- ★ Level of control = fair to good
- ★ REI-12hrs PHI= 21d

Bifenthrin (Capture)
- ★ Control= fair
- ★ Can be applied through irrigation
- ★ Has good residual control
- ★ May kill beneficials
- ★ REI-24hrs PHI= 30d

Pipeline pest management tools:
- ★ None indicated

Other pest management aids:
- ★ None indicated

"To do" List
Regulatory needs
None indicated
Research needs
East: Research pesticide efficacy towards armyworms
East: Research potential for BT wheat to prevent armyworm movement to corn from maturing wheat fields.
Education needs
East: Educate growers on how to use new products for armyworms as they become available
East: Educate growers on what products are most effective for armyworm control

13. Twospotted spider mite [*Tetranychus urticae* Koch] and Banks Grass Mite [*Oligonychus pratensis*]
Western region: No comments were provided for this pest.
Biology and Life Cycle:
Twospotted spider mite has very broad host range, reproducing on grass and broadleaf crops and weeds. Banks grass mite is restricted to grassy crops and weeds. Both species have high

reproductive rates, and short life cycle and can produce multiple generations in a growing season. Spider mites feed on the underside of lower leaves, moving up the plant as populations develop. They feed by sucking juices from leaf cells, leaving yellow dots where they feed. When abundant they can kill leaves. Infestations at the level of the ear often cause economic yield losses. Populations may increase after insecticide applications made for other insects, because broad spectrum insecticides kill predatory insects and mites which help suppress mite population growth. Populations may rebound quickly after miticide application, because except for propargite, miticides are not effective against eggs, and miticides also kill mite natural enemies (predatory mites and insects).

Pest Distribution and Importance:

- Spider mites are controlled during most years by a naturally occurring disease and arthropod natural enemies (predator spider mites and insects). 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, re-treatment may be needed.
- In the **eastern Corn Belt** region it is not considered a pest of importance on corn. More commonly they are a pest in the **western Corn Belt**.
- Two spotted spider mites are less susceptible to most pesticides than Banks grass mite.
- Banks grass mite may colonize corn early in the season as small grains or pasture grasses mature. Two spotted spider mites normally colonize corn later in the season (late whorl-reproductive stages)

Chemical controls: spot treatments are recommended if only part of the field is infested; re-infestation and resurgence is possible after treatment due to egg hatch and destruction of beneficial insects and mites.

Organophosphate

Dimethoate (Cygon 400) @ 1 pt. per acre. Do not use for forage or straw.

- ★ Level of control = fair
- ★ REI-48hrs PHI= 14d

Organosulfite

Propargite (ComiteII) 2.5 qt per acre

- ★ Used more in the West
- ★ Level of control=
- ★ REI=7d PHI -30d
- ★ Only miticide with ovicidal activity

Pyrethroids

Bifenthrin (Capture) 2EC 2.1 to 6.4 fl oz per acre

- ★ Used more in the west
- ★ Level of control = fair
- ★ REI-24hrs PHI= 30d

Pipeline pest management tools:

- ★ None indicated

Other pest management aids:

- ★ Bt corn hybrids may decrease mite outbreaks by decreasing use of broad spectrum insecticide for corn borers.

"To do" List

Regulatory needs

None indicated

Research needs

East: Research product efficacy toward spider mites

Extension needs

East: Educate growers on how to use new products for spider mites as they become available

East: Educate growers on what products are most effective for spider mite control

14. Grasshoppers (predominantly 4 species: **differential** [*Melanoplus differentialis* Thomas], **twostriped** [*Melanoplus bivittatus* Say], **redlegged** [*Melanoplus femurrubrum* DeGeer], **migratory** [*M. Sanguinipas*])

Western region: no comments were provided for this pest.

Biology and Life Cycle:

- Grasshoppers are common mid- to late-summer pests of corn. 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.
- Adult grasshoppers are better controlled with some of the pyrethroid and carbamate insecticides.

Pest Distribution and Importance:

- Cultural practice of delayed mowing of ditch banks etc will assist in keeping the grasshoppers out of production fields.
- Grasshoppers are considered of low importance to corn production.
- 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.

Chemical treatments:

Organophosphate

Chlorpyrifos (Lorsban 4E)@ 0.5 to 1 pt/acre

★ Level of control =not indicated
★ REI-24hrs PHI= 35d

Methyl Parathion (Penncap-M) @ 2 to 3 pints per acre

★ Level of control =not indicated
★ REI-48hrs PHI-14-21d

Dimethoate (Cygon)

★ Control = good
★ REI-48hrs PHI= 14d

Carbamates

Carbaryl (Sevin)

★ Control = Fair
★ REI-12hrs PHI= 1d

Pyrethroids

Esfenvalerate (Asana XL 0.66 EC) @ 5.8 to 9.6 ounces per acre

★ Level of control =not indicated
★ REI-12hrs PHI= 21d

Cyhalothrin (Warrior) 2.56-3.84 fl oz per acre

Zeta-Cypermethrin (Mustang) 2.9-4.3 fl oz per acre

Bifenthrin (Capture)

★ Control= Fair
★ Has good residual control
★ May kill beneficials
★ REI-12hrs PHI= 30d

Pipeline pest management tools:

★ None indicated

Other pest management aids:

★ Sanitation: Avoid trimming weeds and grass around field border during dry weather to discourage grasshoppers from moving into the corn field.

"To do" List

Regulatory needs

None indicated

Research needs

East: Research efficacy of current insecticides toward grasshoppers

Education needs

East: Educate growers on how to use new products for grasshoppers as they become available

East: Educate growers on what products are most effective for grasshopper control

15. Western bean cutworm (*Loxagrotis albicosta*)

Western region: No comments provided for this pest.

Biology and Life Cycle:

- Western bean cutworm is a pest that can severely damage ears, resulting in potentially large yield and grain quality problems.
- One generation per year; larvae overwinter in soil. Populations survive overwintering best in well drained soils.
- The adults oviposit on upper surfaces of corn leaves or on dry edible field bean leaves. Corn fields in late whorl stage are the most attractive to females for egg laying.
- New larvae are about ¼ inch in length and are dark brown. These larvae feed on pollen and then move to ears where they feed until dropping to the ground and form a subterranean overwintering chamber.

Pest Distribution and Importance:

- Timing of treatments is critical, because once the larvae reach the ear tips they are then shielded from the insecticide.
- Fields treated with pyrethroid insecticides should be monitored closely for subsequent spider mite infestations.
- University of Nebraska recommendations are to scout with the beginning of moth flight in the middle of July. The economic threshold is reached when 8% of the plants have eggs or larvae in the tassel.
- Typically a pest in **Nebraska, Kansas, Colorado; recently has also been found in NW Iowa and southern MN.**

Chemical Controls:

Pyrethroids:

Ambush 2E, 25W permethrin 6.4 - 12.8 oz per acre
Mustang zeta-cypermethrin 1.9 - 4.3 oz per acre
Pounce 3.2EC permethrin 2 - 4 fl oz per acre
Pounce 25 WP permethrin 3.2-6.4 oz per acre
Warrior 1EC lambda-cyhalothrin 1.92-3.20 fl oz per acre
Asana XL esfenvalerate 2.9 - 5.8 fl oz per acre
Capture 2EC bifenthrin 2.1 - 6.4 fl oz per acre

Organophosphates:

Lorsban 4E chlorpyrifos 1-2 pts per acre
Penncap-M methyl parathion 2 - 4 pts per acre

Carbamates:

Sevin XLR Plus carbaryl 2 qts per acre

Other Pest Management Aids:

★ Bt foliar sprays not effective against western bean cutworms

Pipeline Pest Management Tools:

★ Future Bt corn hybrids may provide some suppression

"To Do" List:

Regulatory

None indicated

Research

None indicated

Education

None indicated

Insecticides:
Pesticide classes for the insecticides listed above are indicated in the following table. The table also presents intervals required for Restricted Entry (REI) and for Preharvest Intervals (PHI).

Table 2. Insecticides, Trade Names, REI and PHI, and the Estimated Percent of Acres Treated Annually.

Chemical	Trade Names	Restricted Entry Interval	Preharvest Interval	Percent acres treated
Insecticides and Miticides				
Bacillus thuringiensis	Dipel, MVP, Javelin	4 hrs	0 d	
Bifenthrin	Capture	24hrs	30d	2
Carbaryl	Sevin	12 hrs	1 d	
Carbofuran	Furadan	2-14d	30 d	
Chlorethoxyfos + Cyfluthrin	Fortress	48-72hrs		
Chlorpyrifos	Lorsban	24 hrs	4E 35d 50W 28 d	6
Cyfluthrin	Baythroid	48hr or 72hrs if rain<25in/yr	NA	
Diazinon+Lindane	Kernal Guard	NA	NA	
Dimethoate	Cygon	48 hrs	14	
Esfenvalerate	Asana	12 hrs	21 d	
Fipronil	Regent	24hrs	90d	4
Imidacloprid	Gaucho, Prescribe	12 hrs	7 d	
Lambda-cyhalothrin	Warrior 1 EC	24hrs	21d	
Methyl Parathion	Penncap-M	48 hrs	2-4pts 14 d >4pts 21 d	
Methomyl	Lannate	48hrs	21d	
Permethrin	Ambush, Pounce, Kernel Guard Supreme	12 hrs	30d	
Phorate	Thimet	48hr or 72hrs if ran<25in/yr	30d	
Propargite	Comite	7d	30d	
Spinosad	Tracer	4hrs	28d	
Tebupirimphos	Aztec	48 hrs	NA	
Tefluthrin	Force, Force ST, Proshield (seed trtmts)	0hrs	NA	
Terbufos	Counter	48 hr or up to 72 hr where ave rain < 25 in/yr	NA	

Stored Grain Pests This information on stored grain insects was taken from a Purdue University Publication "**PRINCIPAL STORED GRAIN INSECTS OF INDIANA**".

EAST-WEST NOTE: The following insects are listed as pests of stored grain corn. Due to the limitations of time no comments were provided for these pests during the workshops. Workshop participants did note, however, that educating growers about the alternatives to methyl bromide would be an important educational goal.

Biology and Life Cycle:

- As indicated for each pest in the text below.

Pest Distribution and Importance:

1. Granary weevil (*Sitophilus granarius* L).

This weevil, along with the closely related rice weevil, is among the most destructive of all stored grain insects. The larvae develop inside kernels of whole grain in storage, thus making an infestation difficult to remove in the milling process. In Indiana, the granary weevil is largely a pest of stored wheat, corn, and barley, especially in elevators, mills, and bulk storage. The adult cannot fly, and field infestations do not occur.

2. Saw-toothed grain beetle (*Oryzaephilus surinamensis* L).

Along with flour beetles, the saw-toothed grain beetle is one of the most common insects in stored grain and cereal products. The larvae develop in flour, cereal products, and many other dried foods. For this reason, it is a common pest not only in grain bins, but also in elevators, mills, processing plants, warehouses, and kitchens. In grain bins, it feeds on broken kernels and grain residues.

3. Red flour beetle (*Tribolium castaneum* [Herbst]).

This beetle is 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. Like the confused flour beetle (not pictured), the red flour beetle may impart a bad odor that affects the taste of infested products.

4. Larger cabinet beetle (*Trogoderma inclusum* [LeConte]).

Representing a group also referred to as Trogoderma, the larger cabinet beetle is a scavenger that feeds on cereal products and dried animal matter. The fuzzy, slow-moving larvae — similar to the larvae of carpet, hide, and larder beetles — often are found crawling about on or near the products they infest.

5. Lessor grain borer (*Rhyzopertha dominica* [Fabricius]).

This pest is most common and destructive in warm climates but can spread to any area in transported grain. It is a problem of grain only and not cereal products. The larvae develop inside the kernels of whole grain. The adults also damage grain by boring into the kernels and leaving them covered with powder from the chewed material.

6. Rice weevil (*Sitophilus oryzae* L).

The rice weevil is similar to the granary weevil in both appearance and habits. The name is misleading, however, because it infests other grains besides rice. Adults can fly and, in warm climates, can cause widespread damage to corn, wheat, and other grains before harvest. Although field infestations do not occur in Indiana, post-harvest infestations do. Such infestations originate from shipped-in grain or from already infested storage.

7. 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. In the case of stored ear corn, however, feeding occurs anywhere because the moths crawl among the ears to lay their eggs. 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.

8. Cadelle (*Tenebroides mauritanicus* L).

Both the adult and larvae are large and easy to see. Both stages feed mainly on the germ of stored grains, but may also attack milled cereal products. The larvae leave stored grain in the fall and burrow into woodwork, such as wooden bins or boxcars, to hibernate. They may also burrow into packaged cereal products, thus providing an entrance for other cereal pests.

9. Flat grain beetle (*Cryptolestes pusillus* [Schönherr]).

This is a tiny beetle that feeds primarily on the germ of stored grains, especially wheat. It is readily attracted to high-moisture grain. In fact, under high-moisture conditions, the flat grain beetle may also develop in many cereal products, but is not a common pest in kitchens.

10. Angoumois grain moth *Sitotroga cerealella* [Olivier]).

This is a common and destructive pest of crib ear corn. It also infests stored shelled corn, and other small grains, but attack is confined to the surface layer of grain. Field infestations are common in the southern half of Indiana. The larvae develop within the kernels; therefore, the Angoumois grain moth is not a pest of cereal products. Infestations in homes often occur in stored popcorn or in colored ears of corn kept for decoration purposes. The moth resembles the clothes moth but does not shun light.

Chemical treatments:

None indicated

Pipeline pest management tools:

None indicated

Other pest management aids:

None indicated

"To do" List

Regulatory needs

None indicated

Research needs

None indicated

Education needs

East: Educate growers/elevator managers on stored grain issues - methyl bromide is on the way out

Management of Field Corn Diseases

- Diseases are present to some extent every year and are responsible for reductions in both yield and grain 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.
- Throughout most corn producing states, farmers are utilizing conservation tillage systems that assist in soil and water retention. The presence of a mulch layer from previous crops modifies many of the physical, chemical, and biological components of the soil and its ecosystem. Numerous studies have documented changes in temperature, water retention capacity, soil microbiology, soil tilth and structure, and chemical composition when farmers have modified their tillage from conventional tillage to either reduced or no-tillage systems. These micro-environmental changes can have a significant impact on crop diseases.
- Conservation tillage practices result in a continuing emphasis on seed treatments for corn establishment. Also, a trend toward early planting exacerbates disease producing conditions in both conventional and conservation tillage. Although improved crop vigor and better planting methods will aid in crop establishment, there will be a continued reliance on inexpensive seed treatments for effective disease suppression.
- Population dynamics of root pathogens associated with crop residues may change dramatically as tillage systems change. Fusarium species of fungi, in particular, increase when residues are present. These fungi are common root rotters and also invade corn stalks, causing stalk rots.

Higher disease incidence has also been reported with another common soilborne fungus, Rhizoctonia solani. This fungus infects virtually all common field crops and can reduce early season vigor and growth.

- A third group of fungi that thrive in cool, wet soils are Pythium species. These fungi infect the mesocotyl region of corn (the mesocotyl tissue links the new plant with the primary root system). Mesocotyl infections, causing loss of the primary root system, result in reduced growth or death of the seedling. The cooler and wetter conditions associated with reduced tillage increase activity of Pythium fungi.
- Methods of controlling plant diseases in field corn 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 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.
- A key factor in the management of most corn diseases as indicated by producers throughout the Corn Belt is breeding so that organism-specific resistance and tolerance are maintained and improved. Field corn is a relatively low value crop on an acre-by-acre basis, and by the time that a corn disease breaks out significantly, there are either no effective rescue treatments, or the disease has progressed to the point that rescue treatments are not economically practical.
- The group representing the **western Corn Belt**, noted that breeding for drought resistance may be as important as breeding for crop disease resistance. These are not mutually exclusive efforts. Part of yield suppression from drought-stressed corn comes from the plants being predisposed to infection by pathogens that add to yield losses directly caused by the moisture deficit, and vice versa.
- While it is generally accepted that the focus on high yields in corn breeding has resulted in corn plants with greater overall disease tolerance, grower observations suggest that some of the newest hybrids may have greater susceptibility to plant diseases. It is unclear at this time how plant populations, crop rotations, and other management practices may be contributory factors. If these observations prove to be true, there may be a greater need for foliar fungicide treatments in the foreseeable future.
- 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, field corn is seldom treated with foliar sprays. Seed decay and seedling blights, however, are almost always treated for with fungicidal seed treatments. Seed treatments are highly effective against these diseases and are very economical to use.
- Though a number of fungicidal products and classes are available for plant diseases in field corn, 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, popcorn, or other specialty corn types to field corn diseases. This information is provided because these corn types are relatively prevalent throughout the Corn Belt and they may be a source of inoculum for field corn diseases. Though seed corn is not covered specifically in this document, seed corn lines can be assumed to be more susceptible to all plant

diseases listed below. It can therefore also be assumed that more seed corn is treated for diseases than is field corn.
- 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.

1. Seed Decay and Seedling Blight

Biology and Life Cycle:
- 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.

Pest Distribution and Importance:
- 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.
- Seed/seedling diseases are 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 corn replanted due to seedling blight because of treated seed.
- Seed treatment lasts just long enough to get seed germinated.
- In the absence of seed treatments severe losses would be incurred in localized areas.

Chemical controls:

Phenylpyroles

Fludioxonil (Maxim)
- ★ Level of control = good to excellent, since almost 100% of seed is treated there is little to compare it to.
- ★ Seed comes pre-treated.
- ★ REI-NA PHI= NA

Phenylthalimides

Captan (Captan)
- ★ Level of control = good to excellent (fungal pathogen only, not the oomycetes)
- ★ **West:** Level of control is good overall but is disease specific and can be quite variable
- ★ Older product- industry standard for years
- ★ Is combined with Maxim and other seed treatments to cover weaknesses
- ★ REI-49/96hrs PHI=0d

Phenylamides

Metalaxyl (Apron)

- ★ Level of control = good to excellent (for Pythium species)
- ★ Broad spectrum
- ★ More expensive than alternatives
- ★ Not used much on corn due to cost
- ★ Especially good in cool, wet soils
- ★ Used with Captan
- ★ Seed comes pre-treated
- ★ REI-NA PHI=NA

Mefenoxam (Apron XL)

- ★ Level of control = good (for Pythium and Phytophthora)
- ★ REI-48hrs PHI= NA

Pipeline pest management tools:

Other pest management aids:

- ★ Damping-off is generally controlled by seed treatment with a fungicide on almost all seed corn. This is sufficient in most cases, but not under severe conditions.
- ★ Plant corn when the soil temperature is above 50˚F and soil moisture is not excessive.
- ★ Seeds should not be planted too deep; about 1 1/2 to 2 inches is best, depending on soil conditions.
- ★ Improved field drainage/ later plantings on warmer soils.

"To Do" List:

Research

East: Research: initiate or continue biotech research against seed decay/seedling blight pathogens

East: Research: continue developing chemical controls for seed decay/seedling blight

West: Research early season disease contributions to later season diseases (stalk rots, etc)

West: Research seed protecting polymers

Education

East: Educate pesticide applicators on seed treatment exposure issues for seed decay/seedling blight diseases

East: Educate growers and provide easier access to resources for disease identification

West: Educate growers on correct planting depth of seed

Regulatory

None indicated

2. Root rots

Biology and Life Cycle:

- Root rots of corn are very common, and can be caused by a number of fungal pathogens including *Pythium spp., Fusarium graminearum* and other *Fusarium* species, and *Exserohilum pedicellatum*.
- Root rots occur to some extent in every field.

Pest Distribution and Importance:

- 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 and are considered of minor importance to corn production. But under wet conditions, root rots cause economic losses.
- Root rots are primarily controlled by resistant varieties.
- Root rots are not well understood by growers.

- No products are sold to control root rots, therefore very little research has been done on them.
- Root rots may be mis-diagnosed as another disease/injury.
- Excessive crop nutrients may affect amount of disease.

Chemical controls:

- ★ The seed treatments used for seedling rots and seed decay have some limited effect on root rots.
- ★ No products are specifically available and labeled to control root rots.

Other pest management aids:

- ★ Under good growing conditions losses to root rots are negligible, and control measures are not necessary.
- ★ 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.
- ★ 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.
- ★ There are significant varietal differences in susceptibility.

"To Do" List:

Research

East: Research: Hybrid testing for root rot resistance or tolerance

West: Research what effect does early season insect activity and other plant damage have on mid to late season plant health and disease susceptibility

West: Research to determine to what degree growers can improve soil tilth.

West: Continue the development of resistant varieties to soil plant pathogens.

Education

None indicated

Regulatory

West: Government programs affect how growers provide good drainage in fields.

Foliage and Aboveground Diseases

3. Eyespot Aureobasidium zeae

Western region: No additional comments provided for this pest.

Biology and Life Cycle:

- 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 corn follows corn.
- Eyespot may appear early in the season on lower leaves and again near the end of the season on upper leaves.

Pest Distribution and Importance:

- 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.

Chemical Controls

Ethylenebisdithiocarbamates

Mancozeb, (Dithane, Mancozeb, etc)

- ★ Level of control = Good
- ★ REI-24hrs PHI=40d

Triazoles

Propiconazole, (Tilt)

- ★ Level of control=Good
- ★ REI-24hrs PHI=30d

Strobilurins
Azoxystrobin (Quadris)

- ★ Level of control=Good
- ★ REI-4hrs PHI=7d

Substituted Benzenes
Chlorothalonil,(Bravo)

- ★ Level of control = Variable
- ★ REI-48hrs PHI=14d

Pipeline pest management tools:
None indicated

Other pest management aids:

- ★ Resistant hybrids are available.
- ★ Crop rotation or reducing surface residue through tillage reduces inoculum.
- ★ In reduced tillage systems, resistance and rotation are very important control measures.
- ★ Fungicides can be used to control leaf diseases in corn, but usually they are economical only in seed corn, popcorn, or sweet corn production. More than one application is necessary when conditions are favorable for disease.

"To Do" List:
Research
East: Research: continue hybrid development for eyespot control
Education
None indicated
Regulatory
None indicated

4. Common smut *Ustilago zeae*
Western region: No additional comments provided for this pest.
Biology and Life Cycle:

- 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.
- Sporidia 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.

Pest Distribution and Importance:

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

Chemical controls:

- ★ This disease does not receive chemical treatment.

Pipeline pest management tools:

- ★ None indicated

Other pest management aids:

- ★ Resistant hybrids: some hybrids are less susceptible than others.
- ★ Rotation and tillage will not affect the occurrence of smut, since the teliospores survive well in the soil.
- ★ Avoiding mechanical damage through cultivation can reduce the risk of disease.
- ★ Maintenance of balanced fertility and avoiding herbicide injury also will reduce the risk of disease.

"To do" List:

Research

East: Research: Continue hybrid breeding for common smut control.

Education

None indicated

Regulatory

None indicated

5. Northern Corn Leaf Blight

Western region: No additional comments provided for this pest.

Biology and Life Cycle:

- Northern leaf blight is caused by the fungus *Exserohilum turcicum*, previously called *Helminthosporium turcicum*. There are at least seven races of the fungus.
- The fungus overwinters as mycelium and spores in corn residue. Spores are dispersed by wind and splashing water.

Pest Distribution and Importance:

- 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:

Ethylenebisdithiocarbamates

Mancozeb, (Dithane, Mancozeb, etc)

- ★ Level of control=Good
- ★ REI-24hrs PHI=40d

Triazoles

Propiconazole (Tilt)

- ★ Level of control=Good
- ★ REI-24hrs PHI=30d

Strobilurins

Azoxystrobin (Quadris)

- ★ Level of control=Good
- ★ REI-4hrs PHI=7d

Substituted Benzenes

Chlorothalonil (Bravo)

- ★ Level of control=Good
- ★ REI-48hrs PHI=14d

Pipeline pest management tools:

None indicated

Other pest management aids:

- ★ Northern leaf blight can be controlled by two types of resistance, monogenic or polygenic. The monogenic Ht resistance does not confer resistance to all races of the fungus. Hybrids with an Ht gene may become susceptible if new races appear in the area. Polygenic resistance confers resistance to all races, but the resistance is not as absolute as Ht resistance. The level of polygenic resistance varies among hybrids.
- ★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures.
- ★ Fungicides can be used to control leaf diseases in corn, but usually they are economical only in seed corn popcorn, or sweet corn production. More than one application is necessary when conditions are favorable for disease.

"To Do" List:

Research

East: Research: continue hybrid breeding for northern corn leaf blight.

Education

None indicated

Regulatory

None indicated

6. Northern Corn Leaf Spot *Bipolaris zeicola*

Western region: No additional comments provided for this pest.

Biology and Life Cycle:

- Northern corn leaf spot is caused by the fungus *Bipolaris zeicola*, previously known as *Cochiobolis 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.

Pest Distribution and Importance:

- This disease is favored by high humidity and moderate temperatures.
- This disease rarely occurs in modern hybrids and is not treated with fungicides.

Chemical controls:

Ethylenebisdithiocarbamates

Mancozeb, (Dithane, Mancozeb, etc)

- ★ Level of control = fair to good
- ★ REI-24hrs PHI=40d

Triazoles

Propiconazole, (tilt)

- ★ Level of control=Good
- ★ REI-24hrs PHI=30d

Strobilurins

Azoxystrobin (Quadris)

- ★ Level of Control=Good
- ★ REI-4hrs PHI=7d

Substituted Benzenes

Chlorothalonil, (Bravo)

- ★ Level of control=Good
- ★ REI-48hrs PHI=14d

Pipeline pest management tools:

None indicated

Other pest management aids:

- ★ Resistant hybrids and inbreds are available.
- ★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures.
- ★ Fungicides can be used to control leaf diseases in corn, but usually they are economical only in seed corn, popcorn, or sweet corn production. More than one application is necessary when conditions are favorable for disease.

"To Do" List:

Research

East: Research: continue breeding for resistant varieties helminthosporium leaf spot.

Education

None indicated

Regulatory

East: Regulatory: maintain current registrations for control of existing plant diseases

7. Anthracnose leaf blight *Colletotrichum graminicola*

Westerm region: No additional comments provided for this pest.

Biology and Life Cycle:

- 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 also are hosts and may act as inoculum sources.
- Spores are spread primarily by splashing water.

Pest Distribution and Importance:

- Disease development is favored by wet weather with 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 trends for greater occurrence in recent years.
- Anthracnose is not economical to treat for; normally too late to treat once symptoms are seen.

Chemical Controls:

Ethylenebisdithiocarbamates

Mancozeb, (Dithane, Mancozeb, etc)

★ Level of control = fair to good
★ REI-24hrs PHI=40d

Triazoles

Propiconazole, (Tilt)

★ Level of control =not indicated
★ REI-24hrs PHI=30d

Strobilurins

Azoxystrobin (Quadris)

★ Level of control =not indicated
★ REI-4hrs PHI=7d

Substituted Benzenes

Chlorothalonil, (Bravo)

★ Level of control =not indicated
★ REI-48hrs PHI=14d

Pipeline pest management tools:

None indicated

Other pest management aids:

★ Resistant hybrids are available, but resistance to anthracnose leaf blight and anthracnose stalk rot are not necessarily found in the same hybrid.
★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures.
★ Fungicides can be used to control leaf diseases in corn, but usually they are economical only in seed corn, popcorn, or sweet corn production. More than one application is necessary when conditions are favorable for disease.

"To Do" List:

Research

East:West: Research on inoculum and crop production management systems effect on anthracnose, also development of thresholds and diagnostic tools.

East: Research on remote sensing for anthracnose disease using satellite

Education

West: Develop area wide monitoring system to provide early warning to growers.

Regulatory

None indicated

8. Gray leaf spot *Cercospora zeae-maydis*

Biology and Life Cycle:

- 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.

Pest Distribution and Importance:

- 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 and in areas of irrigation.
- 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.
- The number one or two rated disease across the Corn Belt.
- By the time symptoms are readily apparent it may be too late for control measures.

Chemical Controls:

Ethylenebisdithiocarbamates

Mancozeb, (Dithane, Mancozeb, etc)

★ Level of control = fair
★ REI-24hrs PHI=40d

Triazoles

Propiconazole, (Tilt)

★ Level of control = good
★ Timing is critical
★ REI-24hrs PHI=30d

Strobilurins

Azoxystrobin (Quadris)

★ Level of control = good
★ More expensive than standard
★ REI-4hrs PHI=7d

Substituted Benzenes

Chlorothalonil, (Bravo)

★ Level of control - fair
★ REI-48hrs PHI=14d

Pipeline pest management tools:

None indicated

Other pest management aids:

★ Some hybrids are more tolerant to gray leaf spot, but control is variable and may not be adequate.
★ Crop rotation or reducing surface residue through tillage reduces inoculum. In reduced tillage systems, resistance and rotation are very important control measures.
★ Fungicides can be used to control leaf diseases in corn, but usually they are economical only on very susceptible hybrids or in seed corn, popcorn, or sweet corn production. More than one application is necessary when conditions are favorable for disease.

"To Do" List:

Research

East:West: Continue research breeding for resistant varieties to gray leaf spot
West: Develop better tools to predict the disease and determine thresholds

Education

East:West: Educate/notify growers when disease problems appear, need quick turnaround on diagnosis

West: Educate growers on selection of resistant hybrids especially with corn after corn

Regulatory

West: Educate Regulators on the need for new products especially is current ones lose their registration or effectiveness

9. Stewart's Disease *Erwinia stewartii*

Biology and Life Cycle:

- 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.

Pest Distribution and Importance:

- 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 winter temperatures.
- Monitoring for flea beetles is important.
- Winter annual weed control can reduce concerns with beetles.
- This disease is considered of low to moderate importance to field corn production but economical losses are possible if severe (insect) problem is 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.

Chemical Controls:

★ Control flea beetles, no cost effective treatments for disease

Pipeline pest management tools:

Other pest management aids:

★ 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 corn is highest in weedy fields.

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

★ If flea beetle numbers are extremely high, insecticide applications can reduce the beetle population and disease spread. This will occur only after a very mild winter. In seed production with susceptible inbreds, an insecticide may be justified more often.

“To Do” List:

Research

East: Research: Northern states - evaluate predictive models and fine tune models dealing with survival of flea beetles to reduce Stewart’s wilt.

East:West: Maintain an aggressive breeding program to develop tolerance or resistance to Stewart’s wilt.

Education

East:West: Educate growers on the use of scouting and use of predictive models for mitigation of Stewart’s wilt to help prepare for outbreaks.

Regulatory

None indicated

10. Stalk Rots

Western region: No additional comments provided on this pest.

Biology and Life Cycle:

- 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 *Diplodia sp.*

Pest Distribution and Importance:

- 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 generally considered of minor importance in corn production.

Chemical controls:

None indicated

Pipeline pest management tools:

None indicated

Other pest management aids:

★ 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.

★ 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.

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

"To Do" List:

Research

East: Research development of resistant or tolerant varieties to stalk rots.

Education

East: Educate growers with a continuation of demonstrations for disease tolerance, lodging scores for stalk rots.

Regulatory

None indicated

11. Ear and Kernel Rots

Western region: No additional comments provided on these pests.

Biology and Life Cycle:

11a. 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.

11b. 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.

11c. 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 in storage if grain moisture is 20 percent or above.

Pest Distribution and Importance:

- 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:

None indicated

Pipeline pest management tools:

None indicated

Other pest management aids:

★ Plant more tolerant 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)

★ 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.

- ★ 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. These compounds have some disadvantages. Test molded grain for mycotoxins prior to feeding.
- ★ Dry and market corn immediately. Don't store it.

"To Do" List:

Research

East: Research possible chemical controls of ear and kernel rots in field and after harvest in storage.

East: Research secondary effect of Bt (for corn borer) corn in reducing molds resulting from ear and kernel rots

Education

East: Educate consumers on Bt (for corn borer) corn and benefits of reducing molds resulting from ear and kernel rots

Regulatory

East: Regulatory: expedite research process on biotechnology to deal primarily with toxins from ear and kernel rots

East: Regulatory: harmonization of regulatory processes of biotech (to reduce ear and kernel rots) with export customers

Table 3. Fungicides, Brand Names, REI and PHIs, and the Estimated Percent of Seed or Crop* Treated Annually

Chemical	**Brand Names**	**Restricted Entry Interval** (hrs)	**Preharvest Interval Days**	**Percent Acres Treated**
Fungicides and Bactericides		Applies to foliar applications only	Applies to foliar applications only	Blanks indicate amounts between 0 and 1 percent
azoxystrobin	Quadris	4	0	
captan	Captan	96, 48 w/prot. equip.	0	20
chlorothalonil	Bravo	48	14	1*
fludioxynil	Maxim	(NA)	NA	80
mancozeb	Dithane Mancozeb	24	77 Ext. program	1*
metalaxyl	Apron	(NA)	NA	99
meefenoxam	Apron XL	48	NA	?
propiconazole	Tilt	24	0	2*

12. Nematodes

Western region: No additional comments provided for this pest.

Biology and Life Cycle:

- Nematodes that attack corn are microscopic roundworms, approximately 3/10 to 3/64 inch long.
- There are many species of nematodes that feed on corn. Dagger and spiral nematodes may be the most common and widespread nematodes

Pest Distribution and Importance:

- Every cornfield contains nematodes actively feeding on plants. 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.
- Corn nematodes can feed without causing appreciable yield loss if nematode numbers are low and/or the environmental conditions are such that the corn crop is not stressed.
- Needle nematode probably is the most damaging, but is not widespread. The most important species that is a parasite on corn 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 indicated

Other pest management aids:

★ Management options for control of nematodes on corn are limited.

★ Cultural control strategies such as crop rotation, delayed planting, and alternative tillage have little effect on corn nematode densities and nematode-resistant corn hybrids are lacking.

"To Do" List:

Research

East: Research to determine economic damage from nematodes

East: Research relationship between nematodes and other plant diseases

East: Research relationship between weeds and nematodes and causing further damage to crop

East: Research alternative hosts for nematodes

Education

None indicated

Regulatory

None indicated

Management of Weeds in Field Corn

- A ban on atrazine would result in increased costs for alternative products notwithstanding any considerations of lower yields due to reduced weed control. Initial cost estimates may be overly conservative if the fact that atrazine exerts a suppressive effect on the market price of other corn herbicides is not considered. Weed management programs that are based on crop scouting, sequential herbicide applications, and maximum use rates of 1 lb a.i. atrazine per acre would also increase in cost compared with conventional soil-applied, one-pass herbicide applications that contain 1.2 to 2.0 lbs atrazine a.i. per acre. To such costs can be added an additional $3 to $7 per acre for crop scouting and additional trips across the field may cost $4 to $6 per acre sans herbicide.
- Though overall cost remains a major constraint to widespread planting of glyphosate and glufosinate tolerant hybrids, the cost of glyphosate has declined significantly. In the northern corn belt (e.g. the Dakotas), where fewer atrazine options are available, the Roundup Ready hybrids have been adopted more quickly than in other areas of the corn belt.
- Resistance management and weed shifts are major concerns in areas where glyphosate-resistant soybean are planted on a large percentage of the production acres. Continuous planting of both glyphosate-tolerant corn and soybean invites weed resistance or ecological shifts to more tolerant weed species. Key weed pests have already developed enhanced tolerance to glyphosate in select areas of the Corn Belt, and winter annuals are becoming an increasing problem affecting early spring corn planting because glyphosate has supplanted use of residual herbicides in soybean production which previously suppressed winter annual germination and establishment in the fall.
- The infrastructure to handle a predominantly "post-emergent" weed control system in corn may not exist throughout the Corn Belt. The Spring of 2002 was an example of a year where the application window on corn was relatively narrow, and on many days it is either too windy to spray or fields are too wet to support spray equipment. Strict reliance on post-emergence herbicides would have resulted in many fields going untreated.
- Wind and drift are important issues if regulatory actions impose a greater emphasis on post-emergence herbicide application. If producers depend too much upon post-emergence herbicide programs and EPA puts more emphasis on drift control, then making timely post applications becomes even more problematic for corn producers.
- Atrazine "alternatives" such as mesotrione (Callisto) and isoxaflutol (Balance) have achieved fair to good results with higher rates applied pre-emergence. However, the pricing structure present today makes preemergence applications of these products an unlikely choice for many producers. Rates of these new products can be significantly reduced when tank-mixed with low rates of atrazine (i.e. < 1 lb a.i.) making these applications more cost affordable.
- Research throughout the Midwest has shown that groundwater contamination from atrazine can be a problem in areas where soil conditions allow rapid transport to shallow groundwater. These localized areas, however, represent a minute fraction of corn production acres. (Midwest Studies Provide Some Answers, 1999 MSEA Regional Publication)
- Research shows that attaining 90% control of all weeds in no-till systems occurs less frequently than in conventional-till systems. Two-pass programs provide 90% or higher control more often than one-pass programs regardless of tillage system. The addition of atrazine increases the frequency of attaining 90% control. However, one-pass programs do not provide 90% control when atrazine is not used, regardless of tillage system. (University of Missouri, 10-year study, B. Johnson et. al.)
- Atrazine levels in surface water runoff may be problematic in areas of the Corn Belt characterized by the combination of high rainfall in April and May, land use patterns (e.g. >15% of county acres planted to corn), and soils with moderately high to high runoff potential (i.e. high clay content subsoils with argillic horizons). These areas encompass Major Land Resource Areas 109, 112, 113, and 114. (Atrazine Management and Water Quality, M. Smith et al., Missouri Manual 167) Though research and on-farm demonstrations have shown that atrazine levels in surface water reservoirs can be reduced up to 74% through adoption of weed management programs that utilize crop scouting and sequential herbicide applications, these techniques are not universally adopted.

- In 1997 weed specialists from the major corn producing states were interviewed with regards to losses due to weeds in corn. Their estimates of losses totaled 1.25 billion dollars annually or about $16 per acre. This loss included reductions in yield and quality but did not include costs of control. Losses would have been 30 to 50 percent greater if estimates from all specialists in corn producing states had been included and if all weeds were considered. Typically herbicide expenses range from $15 to $25 dollars per acre and tillage and other mechanical weed control expenses can conservatively average $5 to $15 per acre annually. Combining estimates suggests that costs will average more than $45 dollars per acre for weed control and losses due to weeds.
- Weeds reduce corn yield primarily by competing for water, sunlight and nutrients, thus diminishing total corn yield potential. Heavy weed infestations can also affect harvest efficiency by increasing grain moisture content at harvest and increasing foreign material levels in harvested grain, both resulting in added cost to the producer. Weeds can also harbor or host insect and plant diseases.
- Within this document weeds are grouped in logical categories for discussion purposes. Annual species comprise the majority of the weeds found in corn 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 two-crop rotation system primarily 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.
- Increases in conservation tillage practices have resulted in a greater prevalence of weeds from three different classes; perennial weeds (ex. common milkweed, hemp dogbane, and bigroot morningglory, etc), small seeded grass and broadleaf weeds that produce seeds able to germinate near the soil surface (ex. fall panicum, lambsquarters, pigweeds, etc), and winter annual weeds (ex. common chickweed, henbit, and numerous mustards).
- In addition, weed species that have developed resistance to herbicides have in many cases become more prevalent (ex. shattercane, giant foxtail, cocklebur, kochia, and lambsquarters). The most significant resistant weeds in recent years are the tall and common waterhemp species.

Information on the level of control of weeds for listed herbicides is not given in this section but is presented in an aggregate table at the end of this document.

1. Annual grasses

Biology and Life Cycle:

- Grass weeds germinate at soil depths from 1/8th of an inch to 2 or 3 inches. Seed size and dormancy are the controlling factors for when and where these seeds emerge. Large seeded weeds have greater seed food reserves and can emerge from greater soil depths where moisture is less variable than near the soil surface.
- Weeds germinate at various times throughout the season depending on environmental cues such as moisture availability and soil temperature.
- Weeds produce prolific numbers of seeds which may lie dormant for very brief (2 weeks) or very long (30-50 yrs) periods before germination.
- Weed seeds are distributed by wind, rain, birds, and mechanical harvesting equipment.

Pest Distribution and Importance:

- Annual grasses infest approximately 98% of all corn acres. Many of these are controlled with preemergence herbicide applications and tillage.
- While usually not as competitive as broadleaf weed species, 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.

- See Appendix C for a description of the relative importance of various weeds in the Midwest.

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 corn 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 corn.

1b. Woolly cupgrass (*Eriochloa villosa* [Thunb.] Kunth.)

Woolly cupgrass is a relatively new and potentially serious weed problem in the states of Iowa, Illinois, Wisconsin and Minnesota. 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 many other annual grass weeds. Woolly cupgrass has demonstrated tolerance to most herbicides commonly used for control of annual grasses in corn.

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 tolerance to atrazine, and can be a 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 no-till fields and in areas where popcorn and sweet corn production are prevalent.

1e. Barnyardgrass (*Echinochloa crusgalli*)

This summer annual germinates from 0 to 4 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 pauciflorus*, also *C. longispinus*)

Field sandbur is a summer annual weed common in sandy soils. The bur of field sandbur can injure the mouth of feeding cattle.

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

A warm season grass most often troublesome in the southern region of the Corn Belt. The plants root at the nodes and due to a high root to shoot ratio may be very competitive where moisture is limiting. 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.

1h. Shattercane (*Sorghum bicolor*)

Shattercane is an annual grass that is found primarily 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. 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.

Chemical Controls:

Pre-emergence control of annual grasses: As noted in the table below, both pre and post emergence herbicides are used for annual grass control. 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 corn. EPTC and butylate have decreased in use for corn production due to increased use of conservation tillage and the availability of 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
- ★ Vast experience with all formulations
- ★ Economical and cost effective
- ★ Under right conditions will control some annual grasses post emergence
- ★ An expansion of post applied options (tank and pre-mixes) might reduce per acre rates
- ★ REI- 12hrs PHI-21d

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
- ★ REI- 12hrs PHI-NA

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)

- ★ Not much used-has been replaced by products with better efficacy and less environmental concern
- ★ REI-12hrs PHI-NA

Metolachlor (Dual II Mag)

- ★ Level of control= good to excellent
- ★ Used on No-till acres
- ★ Can be applied early
- ★ Slightly more persistent than acetochlor
- ★ not as good on small seeded broadleaf weeds
- ★ Poor on Woolly cupgrass
- ★ REI-12hrs PHI-30d

Dimethenamid (Outlook)

- ★ Control of grasses is good
- ★ REI- 12hrs PHI-40d

Acetochlor (Harness/Surpass, in FulTime & several others)

- ★ Timing is important
- ★ **West:** Marginal control of sandbur and woolly cupgrass
- ★ **West:** Good on yellow foxtail and waterhemp and other small seeded broadleaves
- ★ Crop safety can be variable depending on weather
- ★ FulTime, as a post treatment, has the potential for some crop injury, other acetochlor formulations also have some potential for crop injury
- ★ REI- 12hrs PHI-21d

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
- ★ Replant options may be restricted
- ★ REI-12hrs PHI-NA

Bleaching

Isoxaflutole (Balance)

- ★ Level of Control=Good but only for low grass pressure
- ★ Better than metolachlor and acetochlor on woolly cupgrass
- ★ Poor on yellow foxtail
- ★ Label restrictions due to water contamination concerns
- ★ Some propensity for crop injury
- ★ REI-12hrs PHI-NA

Mesotrione (Callisto)

- ★ New compound, little known
- ★ REI-12hrs PHI-30d

Shoot inhibitor (Thiocarbamates)

EPTC (Eradicane)

- ★ REI-NA PHI-NA

Butylate (Sutan Plus)

- ★ 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
- ★ REI- NA PHI-NA

EPSP synthase inhibition

Glyphosate (Roundup)

- ★ Broad spectrum
- ★ Low to moderate cost
- ★ Except for glyphosate tolerant hybrids, 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 injury potential for adjacent non-RR crops and non-crop plants
- ★ Easy to use
- ★ Safe for the environment
- ★ Not all markets take a GMO crop
- ★ Tolerance/resistance developing in some weeds and there are concerns about rotation of modes of action
- ★ Time of day can affect efficacy
- ★ REI- 4hrs PHI-7d

Glufosinate (Liberty)

- ★ Level of control=depends on coverage but can be good
- ★ Good for most annual broadleaves and woolly cupgrass
- ★ Must be applied to tolerant hybrids.
- ★ REI-12hrs PHI 70d

Post-emergence control of grasses:

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
- ★ May need to use drop nozzles during appl to reduce crop injury (depends on crop stage)
- ★ Cost may be higher than many herbicides

Nicosulfuron (Accent)

- ★ Excellent post grass control (sometimes no other alternative)
- ★ Good control of sandbur
- ★ Good for rescue treatments
- ★ Potential for resistance development
- ★ Costly relative to other products
- ★ Crop injury potential present but low if timing properly managed
- ★ REI- 4hrs PHI-30d

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

- ★ Primarily broadleaf weed control
- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control except for shattercane
- ★ Broad application window
- ★ May need to use drop nozzles for some applications to minimize injury potential
- ★ REI-12hrs PHI-45-60d

Halosulfuron (Permit)

- ★ Primarily broadleaf weed control
- ★ Poor grass weed control
- ★ Application timing is critical for best weed control
- ★ REI-12hrs PHI-30d

2. Perennial grasses and grasslike weeds

Biology and Life Cycle:

- Although perennial grasses and nutsedges produce seed each year the primary mechanism of reproduction is through vegetative propagation.
- Tillage can be an effective mechanism of controlling perennial grasses but when done improperly may further distribute the weed throughout the field and exacerbate the problem.
- Quackgrass is a cool weather plant and grows aggressively early in the spring and in the fall. The other perennials listed tend to grow more actively during the late spring and summer.

Pest Distribution and Importance:

- 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 perennial grasses have declined in importance.
- See Appendix C for a description ranking of weed importance in the Midwest.

2a. 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.

2b. Wirestem muhly (*Muhlenbergia frondosa*)

Wirestem muhly is a perennial grass that reproduces by seeds and underground rhizomes. It is native to the Midwest. It was not considered a common row crop weed until the 1950's when serious infestations developed in cultivated fields. Delayed seedbed preparation will help control wirestem muhly in corn by bringing rhizomes to the soil surface to dry out.

2c. Johnsongrass (*Sorghum halepense*)

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.

2d. Yellow Nutsedge (*Cyperus esculentus*)

Yellow nutsedge causes 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.

Chemical Controls:

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.

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)

EPTC (Eradicane)

Butylate (Sutan Plus)

- ★ 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
- ★ REI-NA PHI-NA

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
- ★ REI- 4hrs PHI-7d

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, or 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)
- ★ REI- 4hrs PHI-30d

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

- ★ Primarily broadleaf weed control

- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control
- ★ REI-12hrs PHI-45-60d

Halosulfuron (Permit)

- ★ Primarily broadleaf weed control
- ★ Poor grass weed control
- ★ Application timing is critical
- ★ REI-12hrs PHI-30d

3. Annual broadleaf weeds

Biology and Life Cycle:

- 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.
- Weeds germinate at various times throughout the season depending on environmental cues such as moisture availability and soil temperature.
- Weeds produce prolific numbers of seeds which may lie dormant for very brief (2 weeks) or very long (30-50 yrs) periods before germination.
- Weed seeds are distributed by wind, rain, birds, and mechanical harvesting equipment.

Pest Distribution and Importance:

- Each of the weeds listed below has its own distribution range and importance.
- The importance of various weeds is highly dependent upon the prevailing attitudes and herbicide use practices. As herbicide use patterns change weed species change as well.
- See Appendix C for a description ranking of weed importance in the Midwest.

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.

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 and tillage will all help control cocklebur establishment.

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.

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.

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 to wet soils, as seedbed preparation may result in transplanting larger plants rather than destroying them.

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

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.

3l. Waterhemp (*Amaranthus tuberculatus*, *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 herbicides with the ALS inhibition mode of action, as well as to triazine compounds.

Chemical Controls:

Pre-emergence control of annual broadleaf weeds:

Soil applied herbicides need to be in place and evenly distributed throughout the top 1 to 2 inches of soil at the time of weed 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. 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, which 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
- ★ Much experience with all formulations
- ★ Economical and cost effective
- ★ Wide window of application
- ★ Multiple formulations
- ★ REI- 12hrs PHI-21d

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
- ★ REI- 12hrs PHI-NA

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)

- ★ REI-12hrs PHI-NA

Metolachlor (Dual II Mag)

- ★ Lasts slightly longer than other acetamides
- ★ Can be used on no-till and early applied
- ★ More persistent than acetochlor
- ★ Not as good on small seeded broadleaf weeds as acetochlor
- ★ REI-12hrs PHI-30d

Dimethenamid (Outlook)

- ★ REI- 12hrs PHI-40d

Acetochlor (Harness/Surpass, in FulTime)

- ★ Control of all waterhemp species is good
- ★ Crop safety can be variable depending on weather
- ★ Timing is important
- ★ FulTime has some potential for crop injury
- ★ REI- 12hrs PHI-21d

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 corn can not be replanted
- ★ REI-12hrs PHI-NA

Bleaching

Isoxaflutole (Balance)

- ★ Some propensity for crop injury
- ★ Label restrictions due to groundwater concerns
- ★ REI-12hrs PHI-NA

Mesotrione (Callisto)

- ★ New compound, little known
- ★ Wide window of application
- ★ Expensive
- ★ Good for resistant waterhemp (new mode of action)
- ★ REI-12hrs PHI-30d

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 of control of grass and broadleaf weeds (also perennials)
- ★ Good application window
- ★ Low to moderate cost
- ★ Must be applied to tolerant hybrid unless applied prior to planting
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants
- ★ REI- 4hrs PHI-7d

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 is Callisto (mesotrione). Since it is newly registered for corn little is 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.

Sulfonylurea+ Growth Regulator

Clopyralid+flumetsulam (Hornet)

- ★ Some soil residual activity
- ★ Can be mixed with atrazine to increase spectrum of activity
- ★ REI-48hrs PHI-85d

Semicarbazone

Diflufenzopyr+dicamba (Distinct)

- ★ Application timing is critical
- ★ Potential for crop injury is unknown
- ★ Good for bindweeds and Canada thistle
- ★ May be an alternative for atrazine in tank mixes
- ★ REI-12hrs PHI-32-72d

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)

- ★ Control is very rate dependent
- ★ Cost effective
- ★ Crop safety and drift concerns
- ★ Works good for a burndown especially with Roundup
- ★ Breaks down rapidly in the environment
- ★ REI-48hrs PHI-7d

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

- ★ Some residual activity in soil
- ★ Performance spectrum enhanced by addition of atrazine
- ★ Good on toothed spurge and thistles
- ★ Potential for brace root deformation under high temperature and humidity conditions
- ★ REI-12hrs PHI-

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, Accent Gold)

- ★ Excellent post grass control (sometimes no other alternative)
- ★ Has good control of some broadleaf weeds
- ★ Crop injury potential (hybrid sensitivity) proper timing essential
- ★ REI- 4hrs PHI-30d

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

- ★ Primarily broadleaf weed control
- ★ Combination products are broader spectrum (NorthStar, Exceed, Spirit)
- ★ Poor grass weed control
- ★ REI-12hrs PHI-45-60d

Halosulfuron (Permit)

- ★ Very good control of some annual broadleaf weeds
- ★ Poor grass weed control
- ★ Application timing is critical
- ★ REI-12hrs PHI-30d

PPO inhibitor

Carfentrazone (Aim)

- ★ Relatively new product and new chemistry. Advantages and disadvantages are not all known at the time of this writing. It does have a relatively narrow weed control spectrum. However, new chemistries are always welcome from the perspective of managing resistant weed development.
- ★ REI-12hrs PHI-

Photosystem II inhibitors

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

Pyridate (Tough)

- ★ In some situations may cause crop injury
- ★ Applicators must be extremely careful with sprayers using air-assist booms
- ★ REI-12hrs PHI-68d

Bromoxynil (Buctril, in Buctril-Atrazine)

- ★ Moderate to good crop safety
- ★ Requires good coverage for control
- ★ No soil residual for late emerging weeds
- ★ Needs tank mixing with other products for acceptable activity on many weeds
- ★ REI-12hrs PHI-30d

Bentazon (Basagran, in Laddok)

- ★ Good crop safety
- ★ REI-12hrs PHI-21d

EPSP synthase inhibition

Glyphosate (Roundup)

- ★ Broad spectrum of control of grass and broadleaf weeds (also perennials)
- ★ Good application window
- ★ Safe for the environment
- ★ Must be applied to tolerant corn hybrids
- ★ Low to moderate cost
- ★ Time of day of application affects efficacy
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants
- ★ REI-4hrs PHI-7d

Glufosinate (Liberty)

- ★ Must be applied to tolerant corn hybrids
- ★ REI- 4hrs PHI-70d

4. Perennial broadleaf weeds

Biology and life cycle:

- While perennial weeds do produce seeds, the majority of plants listed propagate through vegetative means.
- Most perennial weeds begin growth early in the season before crops are planted and may also have a very active period of growth after the crop has been harvested.
- Tillage can be effective for controlling many perennial weeds but it may also distribute viable rhizomes, roots, and tubers throughout the field if done improperly.

Pest Distribution and Importance:

- 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.
- Currently all of the weeds listed below could be considered a more serious problem than they were 5 to 10 years ago.
- See Appendix C for a description ranking of weed importance in the Midwest.

4a. Common Milkweed (*Asclepias syrica* 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, rhizom-like 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 corn rows in vines reducing corn growth and yield. The extensive mass of vines also makes harvest very difficult.

4d. Hemp dogbane (*Apocynum cannabium*)

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* Muhl. ex Willd)

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.

4g. Pokeweed (*Phytolacca americana*)

Pokeweed is becoming more important as a weed throughout the eastern section of the Corn Belt. It tends to be hard to kill and severe infestations can cause contamination of grain that can result in its rejection by elevators.

Chemical Controls:

Pre and Post emergence control of perennial broadleaf weeds: While much of the effort to control perennial weeds takes place before the crop is planted or after it has been harvested, effective control of perennial weeds often necessitates control efforts during the cropping season as well. The control ratings for some of the more common perennial broadleaf weeds are included in a table at the end of this section. Other perennial 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 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 from the fact that there 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, which 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
- ★ Safe for the environment
- ★ Must be used on tolerant crop when used post emergence
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants
- ★ REI- 4hrs PHI-7d

Growth Regulator

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

2,4-D (Many)

- ★ The ester formulation is particularly effective for perennial 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
- ★ Cost effective

- ★ Good for use in burndown applications and as a tank mix with Roundup
- ★ Breaks down rapidly in the environment
- ★ Control is rate dependent
- ★ REI-48hrs PHI-7d

Dicamba (Clarity, Banvel, in NorthStar, in Marksman)
- ★ Some residual activity in soil for annuals
- ★ Good crop tolerance
- ★ Good on Canada thistle, musk thistle, and field bindweed
- ★ Potential for brace root injury under high temperature and humidity conditions
- ★ REI-12hrs PHI-

Photosystem II inhibitors

Bentazon (Basagran, in Laddok)
- ★ Effective on Canada thistle (Good)
- ★ Good crop safety
- ★ REI-12hrs PHI-21d

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

5. Winter Annual Weeds and Cover Crops

Biology and life cycle:
- 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.

Pest Distribution and Importance:
- 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 Corn Belt**, while others such as bluegrass and bromegrass tend to be more of a problem across the **southern section of Missouri, Illinois, Indiana and Ohio**.
- Weeds present in the field early in the season may attract damaging insects and provide an environment for egg laying.
- See Appendix C for a descriptive ranking of weeds in the Midwest.

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 that 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.

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 times, 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 broadspectrum herbicide, or a tank mix of two herbicides capable of killing both the grass and the legume, will be necessary for control.

Chemical Controls:

The following herbicides are commonly used for burndown of winter annual weeds or cover crops. Various combinations of these products may be used depending on the weed species present and the size of the weeds. Added to this list could be metolachlor, although it must be applied early enough to actually prevent winter annuals from germinating or allow time for the herbicide to move into the root zone for absorption through the root system.

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
- ★ Economical and cost effective
- ★ Wide window of application
- ★ Multiple formulations
- ★ REI- 12hrs PHI-21d

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
- ★ REI- 12hrs PHI-NA

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
- ★ Safe for the environment
- ★ Must be used on tolerant crop when used post emergence
- ★ Potential for weed resistance development (although low if properly managed)
- ★ Drift to adjacent crops and non-crop plants
- ★ REI-4hrs PHI-7d

Growth Regulator

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

2,4-D (Many)

- ★ Good for most mustard species
- ★ It can also be used to accelerate the uptake of glyphosate for improved control of other broadleaf perennial weeds.
- ★ Cost effective
- ★ Good for use in burndown applications and as a tankmix with Roundup
- ★ Breaks down rapidly in the environment
- ★ Control is rate dependent
- ★ REI-48hrs PHI-7d

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

- ★ Some residual activity in soil for annuals
- ★ Good crop tolerance
- ★ Good on Canada thistle, musk thistle, and field bindweed
- ★ Potential for brace root injury under high temperature and humidity conditions
- ★ REI-12hrs PHI-

Tillage

- ★ Tillage is an effective method of controlling winter annual weeds and cover crops. However, tillage may not always be practical due to conservation requirements or soil conditions.
- ★ The soil erosion that results from tillage may preclude its use on many soils

6. Herbicide Resistant Weeds

A number of weed biotype populations have been identified as having resistance to one or more herbicide classes. Those most commonly 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 that 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.

No further information was provided for herbicide resistant weeds.

Weed and Herbicide "To DO" list for the Eastern Corn Belt Region for research, education, or regulatory action.

East Region.

Regulatory: Maintaining registered uses of atrazine and the triazine compounds for corn production.

Educate regulators that atrazine is an important weed resistance management tool and controls many newly appearing weeds.

Educate consumers and regulators on the vital role of atrazine to the corn industry. This includes conveying an understanding of its many benefits to growers; applicator safety, crop safety, synergistic effect with other products, wide spectrum of activity, residual activity, burndown activity, cost effectiveness, efficacy, and lack of suitable alternatives for some uses. It was also thought to be important to stress that water quality issues have been addressed by industry/producers through proactive approach/education and that effective stewardship programs are in place throughout the Corn Belt.

Research: Research is needed to evaluate current stewardship programs in a systems approach. Do they compromise the growers ability to control weeds by prohibiting to the use of some cultural treatments unnecessarily? Do restrictions on tillage encourage winter annual weeds and a concomitant increase in the need for herbicides and insecticides?

Research is needed to identify weeds that may develop resistance before it is observed in the field. Need to develop a resistance risk standard for the different types of chemicals and weeds controlled. This may also include the importance of atrazine as a weed resistance management tool.

Research that predicts weed shifts under hypothetical scenarios where product choice is limited (i.e. lack of residual herbicides and its affect on winter annuals). This can also include the implications of cultural practices, production timing, and production practices on weed populations.

Research needed on the effect of continuous glyphosate use on weed shifts (summer and winter annuals especially) and on the development of resistant weeds.

Research is needed on anti-drift products, nozzles, and other ways to prevent off-site movement.

Research on drainage vs. run-off issues for herbicides - confidence in herbicide remaining where applied

Research on the efficacy of fall applied herbicides. (Time of application, effect on winter annuals, environmental effect)

Research on yield drag/lag of biotech hybrids

Research to determine the potential for bur cucumber, nightshades, pokeweed, marestail, white cockle, woolly cupgrass, kochia, fall panicum, prickly sida, waterhemp, dandelion, morning glory, winter annuals to be candidates for future weed shifts

Research to determine if there is a change in the biology of winter annuals that makes them more prevalent now than in the past. Determine the role of fall/spring weed management on winter annuals.

Research to determine impact of winter annuals on corn diseases and insect prevalence.

Research: Research is needed to develop additional agronomic and consumer oriented (output) traits through biotech (value added for end user). Educate public that biotech can be beneficial to production and the environment.

Research: Research is needed on the long term-large-scale systems approach including economics and yield and multi-pests while addressing no-till. The current decrease in no-till corn can be attributed to pest management issues related to conservation programs. (I.e. How can we no-till corn again and still control insects, weeds, and diseases?)

Education: Educate public on benefits of adoption of GMOs. There may need to be some research on how best to do this.

Educate Modes of Action should be stressed to a greater extent in University weed control recommendations. Education should stress Modes of Action that are less likely to allow resistance development.

Educate growers/applicators on how to maintain usefulness of glyphosate and avoid weed shifts and resistance. This includes a focus on all alternative control practices (i.e. system approach)

Educate growers/applicators more on liability issues and the negative impact drift has on entire industry as well as educating rural residents/others who may be exposed to herbicide drift- Right to Know.

Educate growers in systems approach to keeping herbicides out of the water and off the TMDL list.

Educate consumers that producers are addressing water quality - taking a proactive approach and are good environmental stewards. Provide consumers with the real facts regarding risks associated with herbicides in water.
Educate growers on marketing issues - know before you grow - make sure you have a market for your biotech crop.
Educate growers on hybrid sensitivity to various herbicides.
Education: growers need additional management information on 'systems' approach to control.
Regulatory: Maintain current registered uses of atrazine and the triazine compounds for corn production. Consumers and regulators need to know the vital role of atrazine to the corn industry. This includes conveying an understanding of its many benefits to growers; applicator safety, crop safety, synergistic effect with other products, wide spectrum of activity, residual activity, burndown activity, cost effectiveness, efficacy, and lack of suitable alternatives for some uses.
Regulatory: Chemical companies should find ways to make mode of action information a higher priority on labels.
Regulatory resistance management needs to be a more significant part of product labeling with stress on rotation of chemicals with different modes of action. May need to be part of the product registration process?
Regulatory: Find ways to assist the EPA in using current production practices and real world data to evaluate re-registration of products.
Regulatory: Harmonization of biotech regulatory processes with export customers is necessary.

Weed and Herbicide To DO" list for the Western Corn Belt Region for research, education, or regulatory action.

Research: Better understand weed biology/ecology.
Research: Develop variable rate/site-specific options for in-field weed management.
Research: Better understand potential development of Roundup resistance, especially problem weeds.
Research: Maintain research and development money on special new active ingredients, considering Roundup Ready technology.
Research: Examine the use of cover crops and crop rotation for weed control.
Research: Examine the interrelationships between crop nutrient levels, plant health and their impacts on weed establishment, and insect and plant disease infestation.
Research: Examine both alternate-host plant management for insects and diseases, and determine the weed species that could serve as trap crops in corn production.
Research: Develop post-emergence foxtail control measures in no- or low-till situations *(in addition to Accent).*
Research: Develop better alternative strategies on waterhemp control.
Research: Better understand weed shifts and develop a weed-shift prediction model.
Research: Better understand the molecular and genetic basis of weed resistance.
Research: Better understand the effect of adjuvants on performance of herbicides.
Research: Better understand herbicide and corn variety interactions.
Research: Examine the possibilities of weed gene flow from herbicide-resistant crops to weeds.
Research: Determine herbicide rate tolerance by waterhemp and other weeds for available products.
Research: Examine the relationship between herbicide applications and yield *(yield drags).*
Research: Determine what are true yield drags on corn lines resulting from insertion of transgenic traits.
Education: Share information on the performance and role of adjuvants on herbicide efficacy.
Education: Share improved technologies on drift and drift control.
Education: Communicate basic information about weed biology in corn fields and continue compiling information about weed growth characteristics.
Education: Enhance pesticide certification programs with information on application techniques, specifically nozzle selection for given situations.
Education: Heighten awareness among producers and applicators that public concern is raised when misuse or mishandling incidents occur and those concerns are generalized to all products and sometimes all parts of the industry indiscriminately.
Education: Educate growers as to the potential risk factors for off-target movement of atrazine and other products.

Table 4. Weed Control Ratings from Various Weed Management Practices

Blank=poor control or unknown (Product/practice not used) F=fair control G=good control E=excellent control	1. Barnyard grass 2. Wild proso Millet 3. Crabgrass			4. Fall Panicum 5. Foxtails, 6. Woolly Cupgrass 7. Field Sandbur				1. Shattercane 2. Johnsongrass 3. Quackgrass 4. Nutsedge				1. Morningglory 2. BurCucumber 3. Cocklebur 4. Jimsonweed				1. Common Ragweed 2. Giant ragweed 3. Smartweed 4. Wild SunFlower 5. Velvetleaf					1. Pigweed/waterhemp 2. Lambsquarter 3. Kochia 4. Nightshade				**Winter Annuals** 1. Bromegrass 2. Henbit/chickweed 3. Horseweed 4. Mustards			
PPI & PRE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Atrazine 90DF	G	F	F		F		F			F	F	G	F	G	E	E	F	E	F	F	E	G	G	G	F	G	G	E
Princep-simazine	G		F	F	G							G		G	G	G	G	F	F	F	E	G	F	G	G	G	G	E
Micro-Tech-alachlor	E	G	E	G	G	F	F				F										G	F		G				
Dual II Mag-metolachlor	E	G	E	E	G	F	F				F		F					G	G	G	G	F		G				
Frontier-Outlook dimethenamid	G	F	E	E	G	F	F				F										G	F		G				
Surpass/Harness-acetochlor	E	G	E	E	G	G	F				F			F	G	F					E	G		G				
Axiom-flufenacet	G	G	E		G	F	F				F					F					G	G		F				
Prowl-pendimethalin	E	F	G	G	G	G	G														G	G	F					
Balance-isoxaflutol	G	F	F		G	G							F		G	G		G		G	G	G	G	G		F		
Epic-flufenacet-isoxaflutol	E		G		F	G							F		G	G		G		G	E	G	G	G				
Hornet-clopyralid+flumetsulam														G		G	F	G	G	G	G	G	G	G				
Eradicane/Sutan-EPTC&Butylate	E	G	E	E	E	G	G	G	G	F	G									G	G	F	F	G				
Python-flumetsulam														F	G			G	G		E	G	G	F				
Callisto-mesotrione		F																G	F	G	G	G		G				
POST																												
2,4-D amine												E		E	F	G	G	F	G	G	G	G	F	F			G	E
Clarity-dicamba												E	G	E	G	E	G	G	G	F	G	G	G	G		E	F	F
Distinct		F										E	F	E	G	E	G	G	G	G	G	G	G	G				
Stinger														E	G	E	G	F	G					G				
Accent-nicosulfuron	E	G		G	G	G	G	E	E	G		G	G		G			G			G							
Accent Gold	E	G		G	G	F	G	G	G	F		G	F	G	G	G	G	G	G	G	G	F	F	F				
Aim-carfentrazone'		F										G			F			F		G	G	G	G	G				
Beacon-primisulfuron				F				E	G	G	F	6	G	G	G	G	G	G	G	F	G	6	G	G				
Basis	G	F		F	G		F	G	F	F				F				G	G	G	G	G	F					
Basis Gold	G	F		G	G	F	F	G	F	F		G	F	G	G	G	F	G	G	G	G	G	G	F				
Exceed/Spirit-prosulfuron+primisulfuron								E	F	F		F	G	E	E	G	G	G	G	G	E	G	G	G				
Lightning	G		G	G	G	G	G	E	G			F		E	G	F	F	G	G	G	E	G	G	G				
NorthStar-primisulfuron+dicamba				F	F	F	F	E			F	G	E	E	G	E	G	G	E	G	G	G	E	G				
Permit-halosulfuron											G	F	F	E	G	E	G	F	E	G	G		F					
Hornet												G		G	G	G	G	G	G	G	F	F	F	F				
Atrazine+Oil	G	F	F		F	F	F			F	F	G	F	E	E	E	G	E	G	E	E	G	G	E				
Buctril-Contour-bromoxynil												F	F	G	E	F	G	G	G	G	F	E	G	E				
Tough 5EC-pyridate								G	G	G		G		G	F		F		F		G	G	F	G				
Roundup-glyphosate (Burndown)	E	E	E	E	E	E	E	G	G	G	G	G	E	E	E	G	G	G	E	G	E	E	E	E	E	E	E	E
Liberty	G	G	G	F	G	G	G	G				G	F	E	E	G	G	G	G	G	G	F	G	G				
Callisto-mesotrione		G												G		G	G	G	G	G	E	G	G	G				
Celebrity	G	G		G	G	G	G	E	G	G		G	G	G	G	G	G	E	G	G	E	G	G	G				
Marksman-dicamba+atrazine												G	G	E	G	E	F	E	G	G	E	E	G	G	G	E	E	E
Basagran-bentazon														G	G	G	G	G	G	F	F	G	F	F				
Laddok												G		G	G	G	G	G	G	E	G	G	G	G				
Adjust Plant/harvest date																												
Tillage								F	F	F	F														G	G	G	G
Paraquat																									F	G		F

Table 5. Herbicide Used on Field Corn, Brand Names, REI & PHIs, and Percent of Corn Acres Treated in 2000.

Chemical.	Brand names.	Re-entry interval	Pre Harvest interval	% Acres treated
		hrs	days	
2,4-D Amine		48	7	8
Acetochlor	Surpass, Harness, Doubleplay	12	21	25
Alachlor	Micro-Tech	12		4
Atrazine	atrazine, Extrazine, Marksman,	12	21	68
Bentazon	Laddok, Basagran,	12	21	2
Bromoxynil	Buctril+atrazine, Buctril	12	30	4
Butylate	Sutan+			
Carfentrazone	Aim	12		1
Clopyralid	Stinger, Scorpion, Hornet	12-48	40-85	9
Cyanazine	Bladex, Extrazine	12		0
Dicamba	Celebrity, NorthStar, Celebrity B&G,	12		29
Diflufenzopyr	Distinct	12	32-72	3
Dimethenamid	Frontier, Outlook	12	40	7
Eptc	Eradicane, Doubleplay			1
Flumetsulam	Hornet, Python, Accent Gold	48	85	10
Flumiclorac	Resource	12	28	
Foe5043	Axiom 68DF	12		2
Glufosinate	Liberty, Liberty ATZ	12	70	2
Glyphosate	Roundup Ultra	4	7	9
Halosulfuron	Permit	12	30	
Imazapyr	Lightning	12	45	2
Imazethapyr	Contour, Lightning, Resolve	12	45	3
Isoxaflutol	Balance	12		3
Mesotrione	Callisto			
Metolachlor	Dual II	12	30	12
S-Metolachlor	Magnum			16
Nicosulfuron	Accent, Basis Gold, Accent Gold,	4	30	15
Pendimethalin	Prowl/Pentagon	12		3
Primisulfuron	Exceed, NorthStar, Beacon, Spirit	12	45-60	9
Prosulfuron	Spirit, Exceed	12	60	4
Pyridate	Tough, Stinger	12	68	5
Rimsulfuron	Basis, Basis Gold	4	30	9
Simazine	Princep	12		2

Appendix A Herbicide Modes of Action

ALS-inhibitors and amino acid derivatives (HRAC code B)
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) (HRAC code C3)
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) (HRAC code C1)
blocks electron flow in PSII (Hill) reaction, preventing electron transfer, excess electrons develop and breakdown cells: atrazine, cyanazine, metribuzin, simazine

Root-mitosis- inhibitors (HRAC code K1)
disrupt mitosis by inhibiting tubulin-spindle apparatus formation during cell splitting: pendimethalin

Shoot inhibitors (HRAC code K3)
inhibition of lipid synthesis but other processes also active: acetochlor, alachlor, dimethenamid, EPTC, flufenacet, metolachlor

Growth-hormone- regulator (HRAC code O)
stimulates irregular cell growth and may loosen connections between cell walls, other processes also active: 2,4-D, clopyralid, dicamba

Pigment synthesis inhibitor (HRAC code F2)
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 (HRAC code G)
inhibits amino acid synthesis EPSP synthase (amino acids are not replaced): glufosinate, glyphosate

ACCase inhibitors (HRAC code A)
inhibits acetyl CoA carboxylase with lipid synthesis in meristem primarily affected, lipids not replenished: sethoxydim, quizalofop, fluazifop, clethodim

PPO inhibitors (HRAC code E)
inhibition of protoporphyrinogen oxidase (PPO) results in development of free radical and lipid: peroxidation (breakdown of chloroplasts ect)

Appendix B Fungicide Modes of Action

Information abstracted from:
http://www.ndsu.nodak.edu/instruct/gudmesta/lateblight/Modified/PDFdocuments/fungicides.PDF
Not all products listed may be registered for field corn.

Protectants
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
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), Chlorothalonil (Bravo, Daconil, Echo, Evade, Equus)
PCNB induces lysis of mitrochondrial membranes
Chlorothalonil inhibits sulfur-containing enzymes

Curatives
Benzimidazoles: benomyl (benlate), Thiabendazole (Mertect), thiphanate-methyl (Topsin-M)
Inhibition of mitosis by preventing polymerisation of beta-tubulin
Dicarboximides: iprodione (Rovral, Chipco 26019), vinclozolin (Ronilan)
Unknown mode of action
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

Appendix C Insecticide Modes of Action

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. Aquatic crustaceans and some fish, though, seem to have analogous hormones and are quite sensitive to these compounds.

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 that 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 or 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 D Active Ingredient and Mode of Action for List

	Active Ingrediant (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	Aryloxyphenoxypropriona tes 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	Aryloxyphenoxypropriona tes A
	Rimsulfuron	Basis, Basis Gold	Sulfonylurea B
	Sethoxydim	Poast	Cyclohexanediones A
	Simazine	Princep	Triazine C1
	Thifensulfuron methyl	Basis	Sulfonylurea B

Appendix E Results of Weed Distribution and Severity Surveys

Three different pest ranking systems have been used and include: ranking by farmer opinion, ranking by prevalence in acreage as determined by scouting, and ranking via the estimates of discipline specialists.

The table below contains estimates of weed severity as estimated by all three methods. The first column showing numerical data was taken from weed specialists from the major corn producing states in 1997. The second column of numerical data was taken from a survey of corn producers in the North Central States. The last column of numerical data is the percent of fields with observed weed infestations as noted from crop consulting records in northern IL and eastern IA.

Weeds		**Ordinal rank of weeds by crop loss.** 1997 survey of specialists in 16 corn producing states [A]	**Ordinal rank of weeds by severity.** 1992 survey of growers in 12 midwestern states [B]	**Percent of fields infested** 1991-1995 scouting records from N. Illinois & E. Iowa [C]
Amaranthus spp	pigweeds	1	4	11
Abutilon theophrasti	velvetleaf	2	5	1
Sorghum bicolor	shattercane	3	26	
*Setaria faberi**	giant foxtail	4	1	2
Apocynum cannabinum	hemp dogbane	5	22	4
Chenopodium album	common lambsquarters	6	8	5
Polygonum pensylvanicum	Pennsylvania smartweed	7	11	8
Ambrosia trifida	giant ragweed	8	2	9
Ipomoea spp	morningglory spp.	9	12	15
Sorghum halepense	Johnsongrass	10	24	
Setaria lutescens	yellow foxtail	11		
Xanthium strumarium	common cocklebur	12	6	10
Agropyron repens	quackgrass	13	13	20
Eriochloa villosa	woolly cupgrass	14		14
Digitaria sanguinalis	large crabgrass	15	19	
Solanum spp	nightshade spp	16	14	18
Panicum dichotomiflorum	fall panicum	17	18	
Echinochloa crus-galli	barnyardgrass	18	15	
Kochia scoparia	kochia	19	20	
Setaria viridis	green foxtail	20		
Cirsium arvense	Canada thistle	21	9	12
Ambrosia artemisiifolia	common ragweed	22	3	21
Cyperus spp	nutsedges	23	10	6
Panicum miliaceum	witchgrass	24		
Mustard spp	mustards	25	17	
Helianthus annuus	common sunflowers	26	16	
Digitaria ischaemum	smooth crabgrass	27		
Datura stramonium	jimsonweed	28	21	
Asclepias syriaca	common milkweed		7	3
Convolvulus spp.	bindweeds		19	19
Salsoli kali	Russian thistle		23	
Cenchrus pauciflorus	field sandbur		25	
Taraxicum officinale	dandelion			7
Ampelamus albidus	honeyine milkweed			13

* All foxtail species were included in the farmer opinion survey under one listing.

[A] 1997 Agricultural Information Services Ltd. 9 Bovingdon Rd, London SW6 2AP. Proprietary study of pest management on 40 US crops.

[B] Aref, Suzanne, and D. R. Pike. 1998. Midwest Farmers' Perceptions of Crop Pest Infestation. Ag. J. 90:6, p819-825

[C] Pike, D. R. and D. Harms. 1998. The occurrence and densities of weeds in Illinois and Iowas as noted from Crop Scouting Records, Unpublished.

Appendix F Results of Insect Distribution and Severity Surveys

Insects	Scientific Name	Ranked by aggregate insect losses. 1997 survey of specialists in 16 corn producing states [A]	Ranked by opinion of severity. 1992 survey of growers in 12 midwestern states [B]
Northern corn rootworm	Diabrotica barberi	1	2
Western corn rootworm	*Diabrotica virgifera* **	2	2
European corn borer	*Ostrinia nubilalis**	3	1
Black cutworms	*Agrotis ypsilon*	4	3
Spider mites	*Tetranychus spp.*	5	6
White grubs	*Phyllophaga spp.****	6	5
Cutworm	*Euxoa spp.*	7	3
Southwestern corn borer	*Diatraea grandiosella**	8	1
Wireworms	*Melanotus spp.****	9	5
Corn ear worm	*Helicoverpa zea*	10	
Seed corn maggot	*Delia platura*	11	
Grasshoppers	*Melanoplus spp.*		4
Aphids	Aphididae spp.		6

* not separated in grower survey
** not separated in grower survey
*** not separated in grower survey

[A] 1997 Agricultural Information Services Ltd. 9 Bovingdon Rd, London SW6 2AP. Proprietary study of pest management on 40 US crops.
[B] Aref, Suzanne, and D. R. Pike. 1998. Midwest Farmers' Perceptions of Crop Pest Infestation. Ag. J. 90:6, p819-825

Appendix G Results of Plant Disease Distribution and Severity Survey

Disease	Scientific Name	Ranked by aggregate disease losses. 1997 survey of specialists in 16 corn producing states [A]
Seedling/root/stalk rot	*Fusarium*	1
Ear/seedling/stalk rot	*Gibberella spp*	2
Anthracnose stalk/leaf	*Colletotrichum spp*	3
Gray leaf spot	*Cercospora zeae-maydis*	4
Seedling rots/damping off	*Pythium spp*	5
Eyespot	*Kabatiella zeae*	6
Diplodia ear and stalk rot	*Diplodia maydis*	7
Nematodes	*Various species*	8
Smuts	*Ustilago maydis*	9
Rusts	*Puccinia spp*	10
Leaf blights	*Helminthosporium spp*	11
Maize dwarf mosaic virus	*MDMV*	12
Aspergillus ear and kernel rot	*Aspergillus flavus*	13

[A] 1997 Agricultural Information Services Ltd. 9 Bovingdon Rd, London SW6 2AP. Proprietary study of pest management on 40 US crops.

Appendix H Pest Infestation Estimates

Estimates of Treatment, Infestations, and Losses from Various Field Corn Pests in the US Corn Belt. Losses do not include cost of control. 1997 data courtesy of AIS Ltd., London, GBr. [A]

		A. Percent of all US. corn acres treated with a pesticide having some efficacy for the pest	B. Percent of all US. corn acres infested but not treated (or treated but retains infestation)	C. Average annual losses on acreage in column B. ($ Millions)	D. States contributing estimates. (No estimates were obtained from S. Dakota for any pest and weed information was not obtained from Missouri.)
Aspergillus flavus	Aspergillus	0.0	12.3	13	Ks,ne
Cercospora zeae-maydis	Gray leaf spot	2.8	16.3	213	Il,in,ia,ks,ky,mi,ne,oh,pa
Colletotrichum framinicola	Anthracnose leaf blight/stalk rot	9.9	12.4	215	In,ky,mn,oh,wi,ny,pa
Diplodia maydis	Diplodia ear rot	9.9	40.4	84	Il,ky,mn,ne,oh,in,wi
Fusarium moniliforme	Seedling/stalk/root/ear/kernel rot	32.9	65.4	556	In,ks,ne,oh,wi,ia,mi,ny,pa
Gibberella zeae	Stalk rot/ear rot	9.9	35.7	310	In,iq,oh,pa,wi
Exserohilum turcicum	Northern corn leaf blight	0.5	15.7	22	In,ne,pa,il,ks,ny,oh,wi
Aureobasidium zeae	Eyespot	0.6	15.8	86	Ia,ne,wi
MDMV	Maize Dwarf Mosaic Virus	0.0	12.4	15	Ne,tx
Puccinia maydis	Common rust	0.6	13.0	26	Ia,ne,tx
Pythium spp	Seed/seedling/root rot	47.6	45.8	129	Il,ia,ny,pa,wi
				1,672	
Agrotis ipsilon	Cutworm	10.7	14.0	80	Il,in,ia,ks,ky,mi,mn,mo,ne,oh,pa,wi
Diabrotica spp	Corn Rootworm species	43.9	41.4	640	Il,in,ia,ks,ky,mi,mo,nd,ne,ny,pa,wi
Diatraea grandiosella	Southwestern corn borer	1.6	2.6	29	Ks,ky,mo
Euxoa spp	Dark sided cutworm	1.2	2.6	11	Nd,mo,wi
Melanotus spp	Wireworm	1.0	3.0	21	Ks,mi,mo,wi
Ostrinia nubilalis	European corn borer	19.8	22.1	578	Il,in,ia,ks,ky,mi,mn,mo,nd,ne,oh,pa,wi
Phyllophaga spp	White Grub	1.4	1.1	26	Ks,mi,mo,nd,wi
Tetranychus spp	Spider Mites	1.2	2.2	42	Ks,ne
				1,431	
Abutilon theophrasti	Velvetleaf	72.4	44.8	147	Il,in,ia,ks,ky,mi,mn,ne,ny,oh,pa,wi
Elytrigia repens	Quackgrass	11.1	6.4	36	Il,in,ia,mi,mn,nd,ne,ny,oh,pa,wi
Amaranthus retroflexus	Redroot pigweed	62.8	21.9	15	Il,in,ia,ky,mi,mn,oh
Amaranthus spp	Other pigweed species	23.0	18.1	145	Ks,mn,nd,ne,ny,pa,wi
Ambrosia artemisiifolia	Common ragweed	38.1	27.0	6	Il,in,ia,ky,mi,mn,nd,ne,ny,oh,pa,wi
Ambrosia trifida	Giant ragweed	32.0	9.8	56	Il,in,ia,ky,mn,ne,oh,wi
Apocynum cannabiunm	Hemp dogbane	4.0	5.7	62	Ks,mi,ne,pa
Chenopodium album	Common Lambsquarters	77.2	24.4	53	Il,in,ia,ky,mi,mn,nd,ne,ny,oh,pa,wi
Cirsium arvense	Canada thistle	5.3	4.5	18	Mi,mn,nd,oh,pa
Convolvus spp	Bindweeds	1.7	0.5	6	Ny,oh,mi
Cyperus esculentus	Yellow nutsedge	33.1	20.7	10	Il,in,ia,ks,ky,mi,mn,ne,ny,oh,pa,wi
Datura stramonium	Jimsonweed	18.1	18.0	3	Il,in,ia,mi,ne
Digitaria ischaemum	Smooth crabgrass	19.4	19.4	3	Il,in,ky,mi,ne,ny,wi
Digitaria sanguinalis	Large crabgrass	36.7	26.1	37	Il,in,ia,ks,ky,mi,mn,ne,ny,oh,wi
Echinochloa crus-galli	Barnyardgrass	2.3	2.2	21	Ne,ny
Eriochloa vllosa	Woolly Cupgrass	6.5	3.0	34	Ia,mn,wi
Helianthus annuus	Common sunflower	1.8	0.6	4	Ks,nd,ne
Ipomoea spp	Morningglory species	28.8	21.6	30	Il,in,ia,ks,ky,ne,oh
Kochia scoparia	Kochia	5.1	5.5	20	Ks,nd,ne
Panicum dichotomiflorum	Fall panicum	34.8	24.6	27	Il,in,ia,ky,mi,ne,ny,oh,pa,wi
Panicum miliaceum	Wild proso millet	5.1	2.5	16	Mn,nd,wi
Polygonum pensylvanicum	Pensylvania smartweed	51.1	30.2	54	Il,in,ia,ky,mi,mn,ne,ny,oh,wi
Setaria faberi	Giant foxtail	81.9	44.6	91	Il,in,ia,ks,ky,mi,mn,ne,ny,oh,wi
Setaria lutescens	Yellow foxtail	8.4	6.6	48	Ks,mn,ne
Setaria spp	Foxtail (unspecified)	2.5	1.7	9	Nd,pa
Setaria viridis	Green foxtail	23.4	2.5	10	Ia,mn,ny,wi
Solanum ptycanthum	E. Black nightshade	30.6	22.2	21	Il,ia,ky,mi,,mn,nd,ne,oh,wi
Sorghum halepense	Johnsongrass	12.4	10.3	47	Il,in,ks,ky,ne,oh,pa
Sorghum bicolor	Wild cane	16.8	13.6	139	Il,in,ia,ks,ky,ne,oh,
Xanthium strumarium	Common cocklebur	52.0	29.8	37	Il,in,ia,ks,ky,mi,mn,nd,ne,oh
				1,205	

[A] 1997 Agricultural Information Services Ltd. 9 Bovingdon Rd, London SW6 2AP. Proprietary study of pest management on 40 US crops.

Appendix I. Corn Rootworm Distribution and Importance:

Western Corn Rootworm (WCR) overcoming crop rotation –

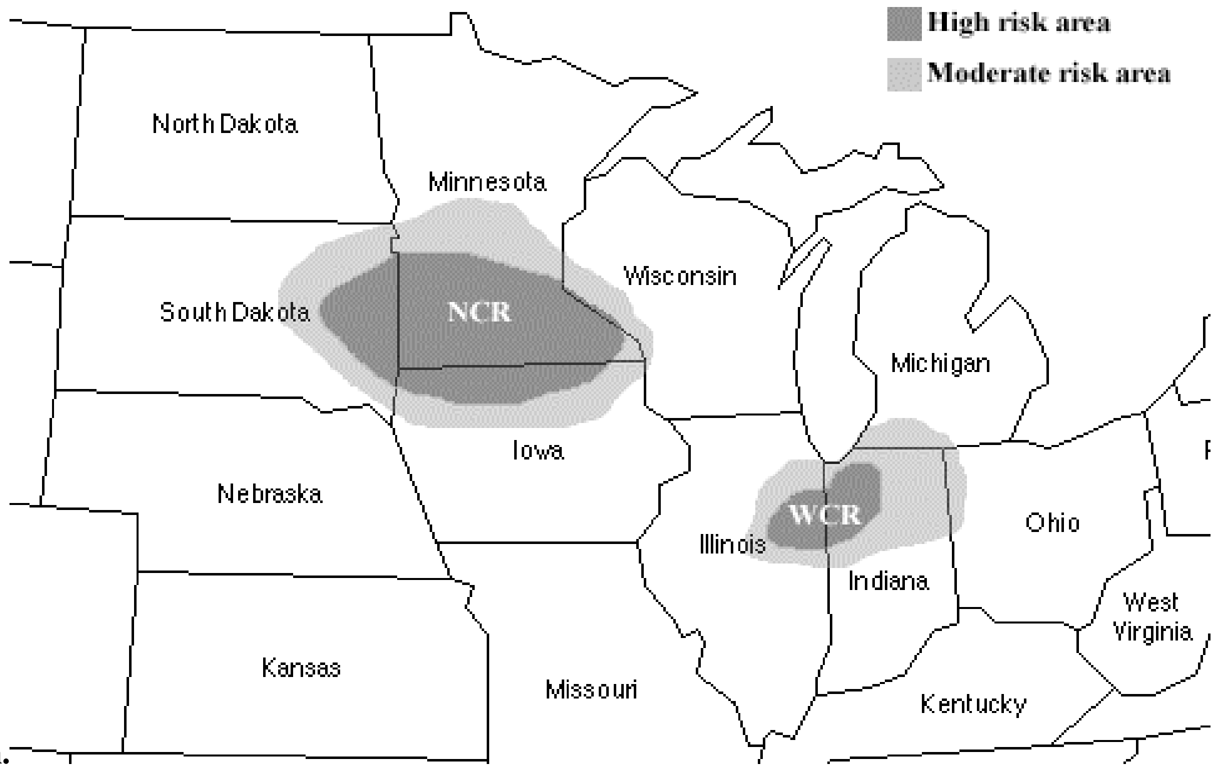
Portions of northern and central Illinois, northern Indiana, southern Michigan, and western Ohio have been affected by a dramatic change in WCR beetle behavior. Previously, WCR adults laid eggs primarily in cornfields. Now, a variant form of WCR beetle lays a majority of its eggs in soybean fields, and has lost its preference to lay eggs in corn. By laying eggs in soybean fields, economic root damage to corn the following season can occur. This behavioral change has virtually eliminated the benefit of crop rotation as a rootworm management tactic in the most severely affected regions of the problem area. Therefore, growers are now using soil insecticides in continuous cornfields, as well as first-year cornfields (primarily fields with a corn/soybean rotation).

At this point, the reason for this dramatic change in behavior is unknown.

Northern Corn Rootworm (NCR) extended diapause –

First-year cornfields in areas of Minnesota, Iowa, Wisconsin, and South Dakota have been extensively damaged by NCR that exhibits an extended diapause trait. Extended diapause is the condition that allows NCR eggs to remain dormant in the soil for not only one, but two winters, as well as through one complete growing season. NCR populations exhibiting this trait, in areas that incorporate crop rotation for rootworm control, have experienced significant rootworm larval damage in first-year corn. Growers in these problem areas are also using soil insecticides in continuous and first-year cornfields.

Problematic areas of NCR extended diapause and WCR eggs being laid in soybean.



soybean.

Appendix J Glossary of Terms Used

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.