HERBICIDE TOLERANCE IN CROPS

PART I

Herbicide tolerance in crop plants is not a new concept. When I grew up on the farm in northern Minnesota during the 1950s, I helped my Dad spray the wheat and barley with 2,4-D to control wild mustard. The wheat and barley were tolerant to the 2,4-D. We also sprayed the farmyard with 2,4-D to control dandelions and other broadleaf weeds. The Kentucky bluegrass and bromegrass were tolerant to 2,4-D. We could not use the 2,4-D to control wild mustard in our alfalfa or sweet clover because the crops would have been severely damaged by the herbicide due to their lack of tolerance.

WALTER R. FEHR

Director of Biotechnology
Iowa State University
1010 Agronomy
Ames, IA soon

As Director of Biotechnology Fehr oversees teaching, research and extension activities. Involved with graduate education and research in plant breeding his specialty is soybean breeding and genetics.

If my father understood herbicide tolerance in the 1950s, why are we discussing it in the 1990s? We are discussing it today because of our ability through biotechnology to make crops tolerant to herbicides that previously would have caused them severe damage. This new ability has raised questions about herbicide tolerance relative to its impact on human safety, environmental safety and the social structure of agriculture. I would like to briefly discuss each of those topics, but first let me review the science that has generated the questions.

Before biotechnology entered the scene, new herbicides were developed by generating an array of new molecules in the laboratory and spraying them on weeds in the greenhouse to determine their effectiveness. If a molecule damaged the weeds, it ultimately was sprayed on crops to determine their level of tolerance. If the crop could not tolerate the herbicide at rates that were needed to damage important weeds, there was no practical way to alter the crop to give it an acceptable level of tolerance, unless there were genetic differences among cultivars within the species. Occasionally,

such genetic differences were found. In soybean, tolerance to metribuzin varied among cultivars. Farmers who used the herbicide had to select cultivars that had an adequate level of tolerance. Some soybean breeders selected for metribuzin tolerance as part of their cultivar development programs.

I suspect that most people never knew that some soybean cultivars were bred for tolerance to metribuzin, at least I do not recall any national conferences at which the practice was debated. So why are we discussing it today? I believe it is an issue today because biotechnology is involved in generating new genes for herbicide tolerance and new methods for transferring the genes among species. I know that some people believe strongly that herbicide tolerant crops (HTCs) developed by the new methods should be called genetically engineered HTCs (GEHTC) or some other designation to distinguish them from the herbicide tolerance that is naturally available in a crop. In the interest of space, however, I will use HTC.

Several methods are being used to develop herbicide tolerance in crop plants. The most simple method is artificial mutagenesis. DuPont developed tolerance to sulfonylurea, sold commercially as Pinnacle®, in soybean by treating seeds of soybean cultivars with chemical mutagenesis. The treated seeds were planted, the resultant plants were naturally self-pollinated, and the self-pollinated seeds were harvested. The seed were sown and the plants were exposed to chlorsulfuron. A mutant plant was found that tolerated the herbicide. The gene conferring the resistance is now being put into high-yielding cultivars by traditional plant breeding methods.

Tissue culture was used by scientists at the University of Minnesota to develop tolerance in corn to the herbicide sethoxydim, which is sold commercially as Poast®. Cells of corn were grown in a media that contained the herbicide. Cells that survived were regenerated into whole new plants, and the regenerated plants and their progeny had tolerance to the herbicide. The gene conferring tolerance to sethoxydim is being transferred into commercial hybrids by traditional plant breeding methods.

A third approach has been used by Monsanto to develop tolerance to glyphosate, which is sold commercially as RoundUp®. They identified a gene in petunia that controlled tolerance to the herbicide. They isolated the gene from petunia and transferred it to soybean by use of *Agrobacterium tumefaciens*. No traditional plant breeding has been used in the Monsanto approach.

Regardless of the method used to develop tolerance to a herbicide, the issues raised about the technology are essentially the same. In fact, past research by soybean breeders in selecting for metribuzin resistance that largely went unnoticed would probably be called into question today.

We are now ready to examine the issues that are being raised about HTCs. For the following discussion, I will rely heavily on the discussion at a conference on HTCs held at Iowa State University (ISU) in October 1990. The report of the proceedings of the conference is published in its entirety in part II of this paper (see page 185). I intend to address only a few of the issues discussed at the conference.

The safety of HTCs for human and livestock consumption has been questioned. If tolerance is extremely high and farmers apply a herbicide at unusually heavy rates, the crop may not be able to completely degrade the compound and a portion of it may end up in the part harvested for feed or food.

There does not seem to be any debate about the importance of determining the safety of HTCs for feed or food consumption. Approval of the Environmental Protection Agency (EPA) must be obtained before a herbicide is registered for use on a crop. This approval will require an evaluation of the presence of the herbicide or any undesirable toxicants.

As a precaution against excessive application of a herbicide, it was recommended at the ISU conference that herbicide tolerance in a crop should be designed to withstand only several times the normal rate needed for weed control. If a farmer used the herbicide at such a high rate that the plant could not break it down, crop injury would occur.

The influence of HTC on environmental safety has been questioned. After listening to many discussions about environmental safety, I have concluded that the concerns are not specific to HTCs, but to herbicides in general. The issues raised about environmental safety also seem to be difficult to separate in most discussions from socioeconomic questions about general herbicide use. Those who oppose HTCs based on environmental concerns are generally the same persons who oppose the use of any herbicide because of its potential influence on the social structure of agriculture.

I would like to separate environmental safety and socioeonomic concerns for a moment because most farmers I know are concerned about the

environment, but do not oppose the use of herbicides for socioeconomic reasons. The use of HTCs will be negative for the environment if they do not result in development of more environmentally safe compounds that can be applied at minimal rates. There are several reasons why I am optimistic that more environmentally safe compounds will be developed through the use of HTCs. First, all chemical companies are keenly aware of the demand by society for safe air, water and food. Second, the EPA is keenly aware of the demand by society for safe air, water and food. Third, state governments are keenly aware of the demand by society for safe air, water and food. This awareness is also shared by farmers, food processors, food manufacturers and food merchandisers.

I am also optimistic that the new compounds used with HTCs will be applied at minimal rates. As a person who has spent his entire life surrounded by farmers, farm magazines and other means of agricultural communication, I have difficulty understanding those persons who equate HTCs with herbicide misuse. I can tell as many stories as anyone else about the misuse of herbicides. I am concerned when farmers, homeowners and other users of chemicals do not treat products with adequate respect for their own personal health and safety. But when it comes to rates of application, I believe the value of the dollar has been and will continue to be the main deterrent to excessive application. I do not know a single farmer who does not consider cost when choosing a herbicide. One of the most important ways to reduce herbicide cost is to reduce the rate per acre. I cannot count the number of articles I have read this winter in farm magazines about banding of herbicides to reduce the cost of weed control. So you must excuse me for not understanding those persons who argue that HTCs and excessive herbicide use go hand-in-hand.

The socioeconomic impact of HTCs is difficult for me to evaluate. Those who express the greatest concern about the negative impacts of HTCs on the social structure of agriculture are generally the same persons who have a clearer picture than I do of what the social structure of agriculture should be in the future. It is argued that HTCs will permit farmers to achieve better weed control more easily, which will permit them to increase their farm size causing a reduction in the number of farmers. My problem with that argument is that weed control is not the factor that determines farm size in the Midwest. Availability of family labor, capital and

land itself seems to be far more important than weed control in determining farm size. I think about the conversations I heard this winter concerning land that was sold in Iowa. Weed control was never mentioned as a reason for buying or not buying the land.

A central issue for U.S. agriculture that pertains to HTCs and other products of biotechnology is the appropriate social structure of agriculture. I have suggested that in the Midwest, farm size will not likely be determined by the presence or absence of HTCs. But what if you believe that HTCs will result in large farms, should that be sufficient reason for prohibiting the sale of HTCs? On whose vision of the social structure of agriculture will we base that decision? Should we use the vision of the National Farmer's Organization, the American Farm Bureau, the American Soybean Association, or a multitude or other farm organization and special interest groups? When I ask the question of vision to farmers in Iowa, the answer is clear. "If a product is considered safe by the federal regulatory agencies, I will decide if it makes economic sense for my operation. I don't need anybody else making my economic decisions."

If we assume that HTCs will be developed and sold in the United States, will they be adopted by farmers, and what precautions, if any, should be taken when they are used? The adoption by farmers will be decided on the basis of the suitability of current herbicides for weed control, the performance of the new herbicide that can only be used with the HTC, and the performance of the HTC cultivars with respect to yield, pest resistance, composition and other important economic traits. It is impossible to generalize about the suitability of current herbicides. Most weeds are adequately controlled through a combination of seedbed preparation, herbicides, mechanical cultivation and hand weeding. At the ISU conference, it was estimated that only five percent of the acreage in Iowa has a weed problem that current herbicides cannot adequately address.

Performance of HTC cultivars will be a major consideration in their adoption. There is no reason for assuming that HTC cultivars with competitive performance cannot be developed. However, adding herbicide tolerance as a selection criterion in a breeding problem will involve more cost for cultivar development. Unless all breeders of a crop insist on having herbicide tolerance in all cultivars, farmers will have a choice between tolerant and nontolerant ones. If HTCs are not competitive, farmers will discriminate against them.

Precautions in using HTCs include factors that relate to all herbicides. To minimize the risk that herbicide-tolerant plants will evolve when a herbicide is used, compounds with different modes of action should be rotated. There is no question that differences in herbicide tolerance among crops has necessitated the rotation of some products. Atrazine was suitable for corn, but not soybean. Treflan®(trifluralin) was suitable for soybean, but not corn. However, Lasso®(alachlor) could be used for both corn and soybeans. Did farmers use Lasso continuously, or did they rotate different herbicides? They generally rotated herbicides because other suitable products were available. If no suitable alternative was available, they probably would have gambled and used the same product on both crops. Therefore, rotation of products with HTCs will probably be determined by the alternatives that are available. The worst thing that could happen would be a reduction by the private sector in their research for the identification of new compounds, with or without the necessity for HTCs.

A second precaution with HTCs is to avoid growing them in areas where they can naturally cross with weed species. If a gene conferring tolerance moves from the crop to a weed, the herbicide will no longer be effective. If is extremely expensive to develop a new herbicide, and it is not in the best interest of the company to have it become ineffective in a short time. This economic incentive for selective use of HTCs in areas without cross-compatible weed species will be important. In addition, farmers will now be interested in products that may create worse problems than they will solve.

I have tried to share with you my overview of the development and use of HTCs. As you can readily discern, my perspective is strongly influenced by living most of my life in the Midwest where herbicides are widely used. The perspective may have been different if I was concerned about forestry, vegetable crops, or other plant species or geographical areas. Other meeting participants will have different perspective to share in the meeting workshops.

PART II

HERBICIDE TOLERANT CROPS: A BENEFIT-RISK ASSESSMENT

The Biotechnology Program at Iowa State University deals not only with the scientific and technical aspects of the application of biotechnology, but also with its possible social and economic impacts. Devoted to the probable risks and benefits of introducing herbicide tolerant crops (HTCs) in Iowa, this paper is the result of a conference held at Iowa State University in late October 1990, which included participants from academia, federal and state government, industry and other selected organizations. The final content of this report is *the responsibility of the Office of Biotechnology, lowa State University, and reflects the opinion of the majority of the participants. Participants at the conference did not necessarily concur with all aspects of the report.*

INTRODUCTION

On October 29-31,1990, a conference was held at Iowa State University to conduct a benefit-risk assessment of the introduction of herbicide tolerant crops in Iowa, and a document prepared to communicate the results of the meeting to the state's policymakers and general public.

Herbicide tolerant crops (HTCs) are crops that tolerate a certain amount of a selected herbicide without damage. Any crop variety must be tolerant in order to avoid injury when a herbicide is applied. Therefore, current crop varieties are herbicide tolerant if they are grown successfully in areas to which a herbicide is applied. Currently, between 30 and 40 herbicides are available in Iowa, but lack of tolerance in some crops restricts herbicide use in the typical soybean/corn rotation.

Increased herbicide tolerance in crop varieties can be developed through various techniques of biotechnology, including tissue culture and genetic engineering. In the context of this report, HTC assumes the use of biotechnological techniques to increase the level of tolerance of a crop to a herbicide beyond what is currently present. Successfully developed HTCs would allow certain herbicides that currently damage corn or soybeans to be used for weed control in those crops.

The purpose of the conference was *not* to determine the advisability of continuing the use of herbicides in agricultural production in Iowa. In-

stead, the focus was: If herbicides continue to be used in Iowa, what is the most probable role of HTCs? Conducting an assessment of the benefits and risks of HTCs assisted the participants in defining the new technology's probable role. The charge given to the conference participants was to concentrate on three areas: 1 - population ecology and genetics; 2 - environmental quality and consumer health; 3 - socioeconomic impacts. During this process, participants were asked to determine the issues on which they could reach a consensus of agreement, to clarify the issues on which they disagreed and why, and to identify areas in which more research is needed.

A brief overview of the major areas of consensus:

—Weed control is critical for crop productivity. Development of effective weed control technologies will continue to be essential for Iowa agriculture.

—Some weeds cannot be controlled effectively using current herbicides because killing the weed also damages the crop plant. Introducing a gene for herbicide tolerance into the crop plant would allow the use of a herbicide that kills the weed without damaging the plant.

—Some herbicides are less desirable for the environment than others. Herbicide tolerance should be pursued only for those herbicides that have minimal negative impact on the environment. Iowa should not seek to increase or even maintain at current use levels those herbicides that are unfavorable to the environment or human health by developing crop tolerance to them.

—The amount of herbicide applied per acre could increase or decrease with the use of HTCs, depending on which herbicides crops are genetically modified to tolerate and how HTCs are incorporated into weed control practices. Since 97 percent of corn and soybean acres in Iowa are currently treated with herbicides, it is logical to assume that the number of corn and soybean acres to which herbicide are applied could only increase by three percent. HTCs will likely lead to displacement of current herbicides with others that potentially may be more favorable for the environment.

—All major crops are already tolerant to many herbicides. Development of HTCs is unlikely to dramatically change the amount of herbicide use for most major crops, but will expand the types of herbicides available for weed control.

—Many farmers use pre-emergence herbicides as "insurance" against potential weed problems. With HTCs, herbicides could be used only when necessary in post-emergence applications, thus reducing the total amount applied.

—Herbicide tolerant varieties of crops should be evaluated by federal regulatory agencies to ensure the safety of the food supply. Current regulations of the EPA require that herbicide residues and their health risks be determined as part of the registration process for any new herbicide or HTC.

—Herbicide tolerance in plants should not be engineered to the point that farmers can over-apply herbicides without harming the crop plants. It is advisable to develop crops that are tolerant to only the minimum amount of herbicide necessary to control weeds, with crop damage occurring if excessive amounts are used.

—Genes for herbicide tolerance should not be introduced into crops where there is a wild weed species with which the crop could intercross. In Iowa, there is no evidence that the movement of a herbicide tolerance gene from corn or soybeans to weeds would be a problem because there are no known weed species in the state with which corn and soybeans can intercross. Each crop into which a herbicide tolerance gene is introduced must be assessed separately for the likelihood that intercrossing with weed species will occur.

—Herbicides used with HTCs should be rotated. If the same or similar herbicides with the same mode of action are used year after year on the same ground, the weeds that withstand it the best will be the ones that survive and produce seed. This natural selection will occur every season. Eventually, these weeds will be numerous enough to again cause a problem.

—It is the responsibility of Iowa State University and its Extension Service to continue to educate farmers about the alternatives for effective, long-term weed control. With so many new technologies becoming available to farmers, only one of which is herbicide tolerant crops, farmers must learn how to integrate the various options into the best management plan for their farm. Optimum weed management strategies should rely on an integrated approach, including crop rotation, cultivation and the minimum use of herbicides.

—Iowa State University should not be involved in the actual development of HTCs. Iowa State University and other public research and educational institutions should continue to invest in researching the appropriate use of herbicides in an overall weed control strategy.
—More research is needed in several areas, including why and how herbicide tolerance evolves or does not evolve in a plant; how to investigate the real dangers associated with herbicide HTCs; how genes flow from crops to weeds; any long-term health risks; possible unintended changes in plant nutrients, natural toxins, or allergens when plants are genetically engineered and treated with herbicides; and integrated weed management systems for agriculture that are unprofitable for the private sector to research or develop.

PURPOSE OF THIS DOCUMENT

The purpose of this document is to communicate to Iowa's policymakers and the public the results of the Iowa State University meeting. It is not written in the highly technical style of a scientific journal because it is not, primarily, for scientists. Neither is it written in the form of a recommendation because its purpose is not to advocate one position over another. Instead, this document is written to inform Iowa's policymakers and public of what some of the top experts believe are the benefits and risks of using herbicide tolerant crops in Iowa.

This document poses questions asked by those examining the role of herbicide tolerant crops in agricultural production. It discusses the answers to those questions as they evolved at the Iowa State University meeting. It pinpoints the questions that remain unanswered. It identifies areas of agreement and disagreement. It is, in short, a written record of the collective expertise of those who attended the meeting.

ISSUES AND ANSWERS

i. What could HTCs do that current herbicide use on crops cannot?

Some weeds cannot be controlled efficiently using current herbicides because killing the weed also damages the crop plant. Introducing a gene for herbicide tolerance into the crop plant would allow the use of a selective herbicide that kills the weed without damaging the crop. This will expand the types of herbicides available for weed control in a crop.

2. *Will HTCs greatly increase herbicide use in Iowa?*

The most recent study available, a cooperative effort between the Iowa Crop and Livestock Reporting Service (now Iowa Agricultural Statistics) and Iowa State University's Cooperative Extension Service, estimates that 97 percent of Iowa corn and soybean acreage receives at least one application of herbicide each growing season (Wintersteen and Hartzler, 1987). There was little change in this percentage during the period of the study from 1979-1985. Since only about three percent of corn and soybean acres do not have herbicides applied now, the number of acres to which herbicides are applied could increase only slightly.

The majority opinion of meeting participants was that the amount of herbicide applied per acre in certain situations could decrease with the use of HTCs. Many farmers use pre-emergence herbicides as "insurance" against weed development later in the growing season. This amounts to applying herbicide for a weed problem before knowing for certain if the weed problem will develop. Environmental factors and cultivation practices affect whether, and how severe, a weed infestation will be. HTCs can allow better post-emergence weed control, allowing the farmer to "wait and see" if a weed problem develops before opting for chemical control. With HTCs, post-emergence herbicides could be used as a clean-up rather than as a preventative.

Scouting a field for insect and weed problems is already being used as an alternative to blanketing a field with herbicide or insecticides as "insurance." Commercial businesses offer the service or knowledgeable farmers can scout their own fields.

All major crops are already tolerant to many herbicides. Development of HTCs is not likely to change the amount of herbicide use, but will expand the types of herbicides available for weed control in a crop. HTCs offer the potential to make more environmentally sound choices among herbicides in certain situations.

3. *Must HTCs have herbicides applied to them in order to thrive?*

One misperception is that a HTC somehow draws its nutrition from herbicides and must be "fed" herbicide in order to live. This is not true.

People who receive a flu shot in the autumn to protect themselves against influenza do not need to have the flu in order to live. However, they can usually withstand exposure to the influenza virus without catching the disease.

It is a similar situation with HTCs. A HTC can withstand an application of herbicide that kills weeds in the field; it does not need the herbicide to live.

4. Will the use of HTCs affect the safety of the food supply?

The conclusion of conference participants was that herbicide tolerant varieties of crops should be evaluated on a case-by-case basis to guard against any potential problems. The International Food Biotechnology Council (IFBC), an industry organization, has proposed a set of guidelines for use by food regulatory agencies. The guidelines are titled *Bio technologies and Food: Assuring the Safety of Foods Produced by Genetic Modification* (IFBC, 1990a).

The majority opinion was that these guidelines should be applied to HTCs just as they would be to any new food product developed through biotechnology. The IFBC published in *Regulatory Toxicology and Pharmacology a* summary of major issues regarding safety assurance of foods produced by the use of biotechnologies (IFBC, 1990b)-

Approval of EPA must be obtained before a herbicide is registered for use on a crop. Environmental Protection Agency registration requirements should also apply to the review of HTCs for commercial use. Participants agreed that two types of tests that should be conducted on new HTC varieties are feeding trials and an evaluation for toxicants. Feeding trials are carefully controlled experiments in which animals are fed grain produced by HTCs and are evaluated for any ill effects. Evaluation for toxicants means the grain would be examined for harmful substances.

The participants agreed that herbicide tolerance in plants should not be engineered to the point that farmers can over-apply herbicides without harming the crop plants. The ideal is to have a crop plant that can withstand several times the normal herbicide strength to insure tolerance, but not 100 times the normal strength. At lower levels, plants metabolize or break down the herbicide, and it is not likely that any would survive in the plant to be passed into the food chain. If a plant could tolerate an extremely high level of herbicide, it is possible that the plant would not be able to break it all down; some might accumulate in the plant and be passed into the grain. The participants agreed it would be advisable to develop crops that are tolerant to only the minimum amount of herbicide necessary to control weeds, with crop damage occurring if excessive amounts are used.

Developing HTCs that suffer injury when herbicides are over-applied also avoids the problem of farmers increasing the herbicide application rate because they do not have to worry about carryover herbicide residues in the soil if the following crop is also herbicide tolerant.

5. *Can the gene for herbicide tolerance accidentally move from the crop into a weed species, making the weed tolerant to the very herbicide used to control it?*

For genes to move from one species to another through natural crossing, the two plant species must be closely related. In Iowa, there is no evidence that this would be a problem for corn and soybeans since there are no known weed species in the state with which corn and soybeans can intercross.

However, the majority opinion of the group was that genes for herbicide tolerance should not be used in crops where there is a wild weed species with which the crop could intercross. For example, shattercane is a weed in fields of its relative, sorghum. Although it would be of short-term benefit if a herbicide tolerance gene could be inserted into sorghum to allow it go be unharmed by a herbicide that kills shattercane, there could be long-term problems. The gene for herbicide tolerance could move from the sorghum into its shattercane relative, making shattercane tolerant to the herbicide.

Oats and horticultural crops in Iowa could encounter similar problems if herbicide tolerant genes were developed for them since they have wild relatives in the state that growers classify as weeds.

The group agreed that each crop into which a herbicide tolerant gene is introduced must be assessed separately for the likelihood that intercrossing with weed species will occur.

6. *Will HTCs promote the development of herbicide tolerant weeds?*

In addition to the accidental movement of a herbicide tolerance gene from a crop into a weed related to it, there is the possibility that if the same or similar herbicides with the same mode of action are used year after year on the same ground, the weeds that withstand it the best will be the ones that survive and produce seed. This natural selection will occur every season, and eventually these weeds will be numerous enough to again cause a problem. The only way to prevent this from happening is to utilize an integrated weed control strategy, including rotation of herbicides with

different modes of action, crop rotation and cultivation. This principle also applies to the appropriate use of currently available herbicides.

The participants' majority opinion was that it is the responsibility of the chemical industry and institutions such as Iowa State University and its Extension Service to educate farmers about the rotation of herbicides with different modes of action as part of an integrated strategy for weed control.

7. *Will HTCs reduce the genetic diversity of weeds that are wild relatives of HTCs but are not a problem in the crop field?*

Genetic diversity within a plant species allows adaptation to and survival of changing conditions. For example, a potato plant that expresses a gene for drought tolerance is more likely to survive a dry spell than the potato plant next to it that does not express that gene so strongly. Nature keeps many different genes in a plant species' repertoire. If a particular gene is needed for the species' survival at some point in time, it will be there.

If wild relatives of herbicide tolerant crop plants somehow receive the herbicide tolerance gene, will there genetic diversity be affected? No. For example, a wild relative of corn is *Tripsacum*. In Iowa, *Tripsacum* is not a weed that appears in corn fields so it is not exposed to herbicide. The majority opinion of the group was that if *Tripsacum were* to somehow receive a herbicide tolerance gene from corn, there would be no problem. Since *Tripsacum* is not a field weed and would not be exposed to herbicides, there should be no selective advantage for the *Tripsacum* plants that have the herbicide tolerance gene over those plants that do not. Both *Tripsacum* with and without genes for herbicide tolerance should survive and their genetic diversity unaffected.

It was the majority opinion that genes for herbicide tolerance quite possibly could be passed to weeds. However, the ecological consequences would be minimal because the weed with the introduced gene will not have a higher survival rate than other weeds in the wild, only in the field. Because natural selection is unlikely to favor the spread of herbicide tolerance genes and alter the genetic structure of wild populations of weeds, it is unlikely that existing genetic diversity would be completely lost from weed species.

8. *Would the development of herbicide tolerant trees increase the use of herbicides in forestry?*

Forestry is a unique crop situation because conventional herbicide and crop rotation practices usually are not utilized. The same trees stay in the same soil for years. Herbicides are currently only used on a fraction of forest acres, but herbicide tolerant (HT) trees are being developed to permit more extensive herbicide use. Some participants believed that HT trees would have little environmental impact since herbicide use on trees would be limited to the first year or two after planting. Other participants felt that expanded herbicide use in forestry was environmentally unacceptable because forests are commonly used for conservation and recreation, as well as for harvesting timber.

Other participants believed there could be a problem with HT perennial plants if multiple applications of the same herbicide were used over a short period of time in short rotation forestry.

One suggestion was that HTCs in trees should be coupled with a sterility system so the herbicide tolerance gene does not spread into the native population of trees.

9. *How would HTCs affect the way farmers manage their crops?*

For farmers who choose to use herbicides as a weed control method, HTCs could increase their flexibility by increasing the herbicide choices and timing of applications.

The participants observed that public sector research must put more emphasis on integrated weed control strategies that minimize herbicide use. With so many new technologies becoming available to farmers, only one of which is herbicide tolerant crops, farmers must learn how to integrate the various options into the best management plan for their farm. Optimum weed management strategies should rely on an integrated approach, which may include crop rotation, cultivation and the minimum use of chemicals.

10. Who bears responsibility for educating farmers about HTCs and their appropriate use?

Attendees saw a need for Extension Service personnel to increase their own knowledge of HTCs and the appropriate use of HTCs. The knowledge could then be passed to farmers. It was agreed that routine use of herbi-

cides should not be promoted. Instead, farmers should understand that herbicides should be used only when necessary and at the rate needed.

Others noted that chemical companies have a great deal to lose in future profits if resistant weeds evolve from the misuse of herbicides, and that there is a need for companies to educate their salespeople and customers on the importance of proper herbicide use.

11. Can farmers with small operations and farmers with large operations both access HTC technology equally?

The majority of participants agreed that the cost of HTCs would not prevent those with small farm operations from using them. However, HTCs might promote larger farms since a farmer might be able to handle more acres with fewer people. Yet other factors such as increased mechanization, the exodus of farm youth from the family farming business, and the greater economic stability of off-farm work may also contribute to larger farms in Iowa.

12. Could HTCs increase yield and contribute to a price decline that could force small farms out of business?

The majority opinion was that HTCs would increase yields only where it became possible to control weeds that are not being controlled now. One member of the group estimated that this might involve 5 percent of the crop acres in Iowa. The only reasons for farmers to use HTCs would be for improved weed control, to lower the cost of production, to reduce the amount of pre-emergence herbicides used, or to provide greater flexibility in the use of more environmentally favorable herbicides.

Wide adoption of HTCs in Iowa might even result in a "yield penalty" for farmers who choose to use them. For example, suppose a company begins research to insert a herbicide tolerance gene into its highest yielding corn variety in 1991. With current technology, the company will spend five to seven years incorporating the gene. By the time the variety is ready for release in 1996, other higher yielding varieties without the herbicide tolerance gene could have been developed. The farmers who choose the 1991 herbicide tolerant corn must pass up the 1996 higher yielding variety and penalize themselves as far as yield is concerned.

13. *What are other possible socio-economic impacts?*

The possible socio-economic impacts of the introduction of HTCs for Iowa include the following:

—No large impact on agriculture is expected.
—Changes in grain quality are unlikely for corn and soybeans.
—There maybe a potential small shift to expansion of farm size due to freeing up labor, but other factors are likely to affect changes in farm size more than HTCs.
—There will probably be a neutral impact on crop yields, unless weeds can be controlled more effectively.
—Farmers are unlikely to be willing to pay higher seed costs, unless there is a savings in herbicide costs or better weed control is achieved.
—Increased options and flexibility in herbicide use are likely.
—HTCs may foster improved soil conservation if they provide more effective weed control in conservation tillage systems.
—An increased level of management skills will be required of farmers to coordinate crop variety and herbicide selection and use.
—The competitive structure of the seed/chemical industry could change.
—HTCs could lead to new regulatory constraints and costs for industries and farmers.

14. Should public research funds be used to develop HTCs?

The majority opinion was that Iowa State University should not be involved in the actual development of HTCs. Iowa State University and other public research and educational institutions should continue to invest in researching the appropriate use of herbicides in an integrated strategy for weed control.

The socio-economic experts suggested that public sector research may shift to developing weed control technologies other than HTCs since industries are doing the HTC research.

15. *Will HTCs allow increasing amounts of undesirable herbicides to enter the ground water, soil, and air?*

The meeting participants agreed that herbicide tolerance should be pursued only for those herbicides that have minimal negative impact on the environment. It was their belief that Iowa should not seek to increase—or even maintain at current use levels—those herbicides that are unfavorable to the environment or human health. HTCs for more environmentally favorable herbicides could replace the more persistent herbicides that can become environmental pollutants.

Since the increased use of one type of herbicide might cause environmental contamination and impact wildlife, it is important that herbicides be used in a rotation so chemicals with the same mode of action are not applied year after year to the same field.

Attributes suggested for herbicides used in conjunction with HTCs include:

—Low toxicity to non-target species, including humans and wildlife.
—Low residues in the environment.
—Non-toxic residues in the crop and food.
—Low threat to ground water, surface water and air.
—Low use rates.
—Appropriate degradation (breakdown) with benign breakdown products.
—Cost effectiveness.
—Compatible with alternative weed management strategies.
—Compatible with technology improvements in the way the herbicide is applied.
—Increased reliability of weed control accompanied by improved crop yields.

16. What are the gaps in knowledge about HTCs; what is an appropriate research agenda?

More research is needed on why and how herbicide tolerance evolves or does not evolve in a crop or weed. The majority opinion was that the amount of basic weed science research and the dollars to support it should both increase.

Perceived versus Real Risks—Society must sort out the perceived dangers versus any real dangers associated with HTCs. For instance, many members of the public perceive that HTCs will cause increased herbicide use in Iowa. Is this a legitimate concern, or is present herbicide use so high that HTCs are unlikely to have a significant impact?

Many of the participants at the meeting viewed the perceived risks of HTCs as the same risks faced today in agriculture when anew herbicide is introduced, such as potential use of higher herbicide rates by farmers, increased dependency on single chemical exposure, new or increased toxic chemical residues in crops, altered plant properties, food residues and less diverse farming systems. In assessing the benefits and risks of HTCs, a dis-

tinction must be made between risks more or less unique to HTCs and risks applicable to any herbicide use.

Gene Movement—More information is needed regarding if and how genes flow from crops to weeds. Is it possible for genes to transfer in ways other than by natural crossing? Is there a non-sexual method of gene transfer? A study should be done to monitor plant population and gene shifts before and following the introduction of an HTC.

Should regulatory agencies try to prevent HTC use in areas where weeds are related to the HTC? Should the technology, once developed, be kept from other countries where it should not be used due to the presence of weed relatives?

Environmental and Health Considerations—Most health risk concerns for HTCs will probably by similar to those associated with currently available herbicides. How will certain HTCs affect the environment? Will there be an increased risk to farm workers who work with HTCs? Are there synergistic factors that work together to increase herbicide health risks? For example, does a person's diet interact with herbicide exposure to increase the risk for disease more than would either diet or exposure alone?

Unintended Plant Responses—Research needs to be done to ensure that plants will not develop unintended changes in nutrients, natural toxins, allergens, etc., when they are genetically engineered and treated with herbicides.

Farm Management Systems—While research on chemical weed management through the use of herbicides is important, some participants at the meeting believe research support in the universities has been skewed in this direction in the past. They suggested that Iowa State University and other agricultural institutions should develop research agendas stressing viable, overall, integrated management systems for agriculture, especially those systems that are unprofitable for the private sector to research.

Can herbicide tolerance genes be developed that encourage rotation of herbicides? Should Iowa avoid introducing tolerance to a herbicide in both corn and soybeans?

Socioeconomic Questions—The sociologists and economists present at the meeting defined the following research questions:

—Which is the best allocation of Iowa's resources, herbicide tolerance or the development of resources?

—Who decides the research priorities for industries and universities?
—What effects will HTCs have on related research and product development?
—How can the self-interest factors of land-grant colleges, the chemical industry and the seed companies be evaluated?
—What is the appropriate method to use in evaluating impacts of a new technology like HTCs?
—What are the public's values and beliefs regarding HTCs?
—What factors influence farmers' and the public's acceptance of HTCs?
—What are the educational needs of farmers and the public concerning HTCs?

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