GLYPHOSATE TOLERANT CROPS IN THE EU

A FORECAST OF IMPACTS ON HERBICIDE USE

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Acknowledgements

This project builds on, and is an extension of past work on the impacts of genetically engineered crops on pesticide use in the United States. Since 2004, I have done three reports on that topic. The most recent quantifies the impact Roundup Ready corn, cotton, and soybeans on herbicide use from 1996 through 2011 (Benbrook 2012). The present analysis focuses on two of these crops (maize and soya), as well as sugar beets, and projects impacts of Roundup Ready (RR) technology in the European Union (EU), assuming RR technology is approved.

I appreciate the help and guidance received from a number of weed scientists, government ministry experts, and pest control specialists across the EU. Unlike the U.S., there are no comprehensive datasets covering pesticide use in major agricultural crops in the EU. For this reason, the information required to establish the herbicide use baselines in this analysis had to be compiled from a variety of sources.

Karie Knoke helped design the simulation model, drawing on her exceptional skills with Microsoft Excel. Karen Benbrook helped locate and refine the datasets, created tables, and prepared the final report.

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List of Acronyms and Abbreviations

a.i. – (pesticide) active ingredient
Bt – Bacillus thuringiensis
CWT – one-hundred weight
ERS – Economic Research Service (part of USDA)
EPA – U.S. Environmental Protection Agency
EU – European Union
GE – genetically engineered plants, also known as genetically modified (GM)
GM – genetically modified plants, also known as GE
GR – glyphosate resistant
GT – glyphosate tolerant
HR – herbicide resistant
HT – herbicide tolerant
IPM – Integrated Pest Panagement
ISHRW - International Survey of Herbicide-Resistant Weeds
km/hr – kilometers per hour
kt - kilotonne
NASS – National Agricultural Statistics Service (part of USDA)
NHL - non-Hodgkin's lymphoma
PDP – Pesticide Data Program
RR – Roundup Ready
SL – surface boundary layer
USDA – United States Department of Agriculture
WSSA – Weed Science Society of America

<u>Conversion Factors</u>:

1 hectare (ha) = 2.47 acres

1 kilogramme (kg) = 0.454 pound (lb)

kg/hectare (ha) = 1.12 lb/acre =

I. Key Findings and Executive Summary

Crops genetically engineered (GE) to tolerate applications of broad-spectrum herbicides account for about three-quarters of the area planted worldwide to GE crops. The vast majority of these herbicide-tolerant (HT) crops are engineered to withstand applications of glyphosate (Roundup), a broad-spectrum herbicide discovered and first marketed by Monsanto.

In deciding whether, and on what terms to approve glyphosate-tolerant, Roundup Ready crops for planting in the EU, policy-makers can and should draw upon lessons learned in the U.S. over the last 16 years. Roundup Ready corn (*Zea mays*), cotton (*Gossypium spp.*), and soya (*Glycine max*) came on the market in 1996 and were rapidly adopted. Since 2000, Roundup Ready technology has formed the backbone of maize, soya, and cotton weed-management systems in the U.S.

But the rapid pace of RR system adoption, coupled with successful weed control on most farms in the first years of use, led to over reliance on a single herbicide (glyphosate), which in turn triggered incremental, but widespread shifts in the species of weeds in crop fields, and ultimately, the emergence and spread of glyphosate-resistant weeds.

In 2012, RR crops were planted on about 65 million hectares in the U.S., about one in every two hectares of cultivated cropland. Between one-third and one-half of the land planted to RR crops (21 to 33 million ha) is already infested with one or more glyphosate-resistant weeds. As a result, farmers have been forced to spray glyphosate more often and at incrementally higher rates, and also must incorporate one to three additional herbicides into their spray programs to deal with the weeds that have become immune to glyphosate. The inflated costs of RR seed and herbicides have cut into profit margins on U.S. farms. Because there are more herbicide-tolerant weeds on the horizon, weed control problems are bound to get worse in the years ahead.

The RR System's Achilles Heel

The dramatic shifts in weed-management technology made possible by genetic engineering have triggered equally dramatic consequences. The RR system in the U.S. is unraveling at about the same pace it was adopted. Already, some two-dozen weeds have evolved resistance to glyphosate, including several of the most damaging, prolific, and hard to control weeds on the North America continent – Palmer amaranth *(Amaranthus palmeri)*, waterhemp (pigweed)(*Amaranthus tuberalatus syn.rudis*), horseweed (*Conyza canadensis*), common ragweed (*Ambrosia artemis*), giant ragweed (*Ambrosia trifida*), kochia (*Kochia scoparia*), and Johnsongrass (*Sorghum halepense*).

Dow AgroSciences, a major player in the U.S. biotech-seed-pesticide industry, advised the U.S. Department of Agriculture (USDA) in a June 2011 regulatory submission that about two-thirds of soya hectares and one-half of maize hectares in the U.S. are already infested with at least one glyphosate-resistant weed (see Chapter IV for details and references).

The glyphosate-resistant weed outbreak is –

"…a train wreck that is not slowing down at all."

Iowa State University weed scientist Mike Owen,
"Weed Denial Not Good" (Lawton 2012)

This is why many U.S. weed scientists are calling for dramatic changes in how the RR system is deployed. A once heretical suggestion -- that government may need to impose restrictions on how often, and widely, an herbicide can be applied – has been made in a prominent weed science journal (Harker et al. 2012).

Yet the biotech-seed-pesticide industry in the U.S. is actually headed in the opposite direction. It is investing heavily in the development of crops resistant to multiple herbicides, in the hope that farmers can spray their way through today's problems with glyphosate-resistant weeds, a strategy as grounded in commonsense as pouring gasoline on a fire to put it out.

RR Technology in the EU

So what might happen in the EU if government agencies approve, and farmers adopt and rely on RR technology much as they have in the U.S.? It will almost certainly trigger increases in the volume of herbicides applied, the emergence and spread of resistant weeds, and higher costs and more intensive herbicide spraying as farmers struggle to deal with increasingly hard-to-control weeds. But how significant might the changes become?

Applications are pending for approval for cultivation of three GE crops in the EU -- RR maize, soya, and sugar beets. A model was developed to project the likely changes in herbicide use across the 27-EU member states, if the planting of these crops had been authorized in time to allow planting in 2012. The impacts of RR technology on herbicide use are projected in 2012 through 2025 under three scenarios, and compared to a 2011 baseline:

- Scenario 1 -- A status quo scenario based on no approval or planting of herbicide-tolerant varieties,

- Scenario 2 -- Unlimited adoption patterned after the trajectory of RR crop adoption and herbicide use in maize and soya production from 1996-2010 in the U.S., and
- Scenario 3 -- Targeted adoption limited by a binding commitment to resistance management, such that no hectare can be planted to back-to-back RR crops.

Maize The volume of herbicides sprayed by maize farmers would likely rise marginally (~13%) across the 27 EU countries in Scenario 1 from 2011-2025, reflecting the net impact of more aggressive weed management and higher yield goals, coupled with continuation of the long-term trend toward low to moderate-dose herbicides and implementation of the EU Parliament's directive on the "Sustainable Use of Pesticides" (see Table 6.1 for maize results).

For maize under "Unlimited Adoption" (Scenario 2), glyphosate use would rise 1,040% above the 2011 baseline, to 22.5 kilotonnes (kt) in 2025. Heavy glyphosate use, however, makes it possible for farmers to drop applications of other herbicides, especially in the early years of adoption. The volume of "Other [not glyphosate] Herbicides" applied falls from 14.6 kt in 2011 to 10.7 kt in 2025, a 27% reduction.

Overall herbicide use in maize in Scenario 2 is projected to double from the 2011 baseline level, rising from 16.6 kt to 33.2 kt.

Glyphosate use rises about 500% in Scenario 3, while overall herbicide use goes up 38%. The 38% increase is about mid-way between Scenarios 1 and 2, and reflects targeted adoption of RR maize varieties, in conjunction with adherence to resistance management provisions that prohibit the back-to-back planting of RR crops.

Soya Soya is a relatively minor crop in the EU. For each hectare in the EU planted to soya in 2011, there were 37 maize hectares and 4.2 sugar beet hectares planted. Soya herbicide use in the 2011 baseline was 0.42 kt, just a fraction of total maize herbicide applications (16.6 kt in 2011) (see Table 6.2 for soya results).

Total herbicide use in soya is projected to fall 12% in Scenario 1 as a result of the ongoing trend toward lower-dose herbicides, coupled with the impact of the "Sustainable Use of Pesticides" Directive.

In Scenario 2, herbicide use is projected to rise from 0.42 kt to 0.94 kt, a 123% increase. This increase is driven solely by rising use of glyphosate. The volume of glyphosate-based herbicides in 2025 across the EU is projected at 0.78 kt, up from 0.050 kt in 2011. For each kg of glyphosate applied in 2011 on soya, 15.6 kg would be applied in 2025. This dramatic increase in reliance on glyphosate by soya farmers is by far the most significant on a hectare-treated basis across the three crops, but the volume of increased glyphosate use on maize from 2011-2025 still dwarfs the volume of the increase on soya.

In Scenario 3 under targeted adoption, the overall increase in herbicide use on soya is estimated at 60%, and is brought about by the projected 662% increase in glyphosate use in 2025, compared to 2011.

Sugar Beets Across the EU in 2011, nine hectares of maize were grown for each hectare of sugar beets, but sugar beets were far more herbicide intensive on a per ha basis. The average ha of sugar beets in the EU was sprayed with 5.1 kg/ha of herbicides in 2011, compared to 1.1 kg/ha in the case of maize. Sugar beet weed management is heavily chemical intensive because weeds must be controlled over a relatively long growing season, and in the absence of a dense and tall crop canopy. Maize and soya crops grow tall enough with ample foliage to shade the ground and slow weed germination and growth, whereas the canopy in a sugar beet field is more open, favoring season-long weed germination and growth.

Roundup Ready sugar beet varieties are projected in Scenario 2 to increase overall herbicide use by 12% (see Table 6.3 for sugar beet results). The volume of glyphosate applied in 2025 rises 377% to 4.9 kt in 2025. "Other Herbicides" decline 39%. Without RR sugar beets, herbicide use is projected to fall 28% in Scenario 1, as a result of the long-term trend toward lower-dose herbicides, coupled with the impacts of the "Sustainable Pesticide Use" Directive.

Impacts Across the Three Crops

Overall herbicide use is projected to decrease by 1% by 2025 in Scenario 1 across the land area planted to the three crops (Table 6.4). The 13% decline in the volume of "Other Herbicides" applied more than makes up for the 88% increase in glyphosate use. Total herbicide use is projected to rise 72% by 2025 under the "Unlimited Adoption" scenario. "Other Herbicides" use would fall 31%, from 22.3 kt in 2011 to 15.3 kt in 2025. The explosive 824% growth in the volume of glyphosate applied accounts for the net, 72% increase in overall herbicide use.

With "Targeted Adoption," total herbicide use would rise 25% by 2025. A 409% increase in glyphosate use accounts for this overall growth in the volume of herbicides applied in Scenario 3.

Today, glyphosate accounts for about 12% of total herbicide use in maize, soya, and sugar beets in the EU (Table 6.5). In 2025 under the "Unlimited Adoption" scenario, glyphosate use rises to 28.2 kt – ***more than total herbicide use in the 2011 baseline.***

Moreover, glyphosate would account for ***65% of the total volume of herbicides applied on these three crops***, a level of reliance sure to trigger the emergence and rapid spread of glyphosate-resistant weeds.

The enormous increase in glyphosate use in Scenario 2 is driven by three factors:

- The much higher portion of the hectares planted to each of these crops that will be sprayed with glyphosate, contingent, of course, on RR varieties being approved and widely planted,
- The gradual increases in the average number of glyphosate applications made on hectares planted to RR varieties, as weed shifts and resistance take hold, and
- Incrementally rising glyphosate application rates per ha, from around 0.9 kg/ha in 2011 to ~1.2 kg/ha in 2025.

The Clock is Ticking

Because substantial quantities of glyphosate have been used over many years in the EU, problems with resistant weeds in RR crops are likely to emerge more quickly than they did in the U.S. Populations of six weeds resistant to glyphosate already exist in several EU member states (see Chapter IV for details). Approval and widespread planting of RR crop varieties will create ideal conditions to accelerate both the spread of already-resistant weeds and the emergence of new ones. Both can move aggressively across areas where a high percentage of cropland is sprayed with glyphosate.

A glyphosate-resistant horseweed (*Conyza canadensis*) plant that reaches maturity produces, on average, around 130,000 seeds. Common waterhemp (*Amaranthus tuberculatus syn. rudis)* sets 400,000 seeds per plant. Resistant seeds can travel 87 to 122 kilometers with wind speeds of just 17.5 km/hr, and can move much farther in extreme weather events (see Chapter IV for details and references). A serious flood along a major river system can disperse resistant-weed seeds for hundreds of kilometers, impacting thousands of hectares of low-lying farmland, which henceforth will serve as both reservoir and well for further, regional dispersal.

In the U.S., it took four years for RR technology to trigger the first, new glyphosate resistant weed (horseweed in Delaware). After 10 years of use in 2005, the glyphosate-resistant weed tipping point occurred as a result of the emergence of GR Palmer amaranth and common waterhemp.

If EU farmers adopt and use RR technology much as U.S. farmers have (scenario 2), the first RR-triggered outbreak of glyphosate-resistant weeds will likely occur in southern Europe within just a few years of commercial use. The time period between commercial adoption of RR crops and the spread of glyphosate-resistant weeds in Spain will be shorter than in the U.S. because there already are several glyphosate-resistant weed phenotypes in that country. Weed populations of the first, hairy fleabane (*Conyza bonariensis*), were confirmed present in Spain in 2004.

Continuous planting of RR crops in the EU for five to seven years would likely hasten the emergence and spread of multiple glyphosate-resistant weeds in many regions. Despite spraying more and more glyphosate, farmers will then have to spray additional herbicides in the 2020 to 2025 period in an effort to combat glyphosate-resistant weeds.

Except on farms converting to organic production, the spread of resistant weeds will inevitably drive herbicide use upward. Industry data from the U.S. show that the presence of resistant weeds in maize fields in the U.S. increases herbicide use by an average 2.02 kg/ha (see Chapter IV for details and references). In soya, the expected increase is 1.23 kg/ha. Increases of this magnitude ***more than double*** herbicide use compared to the lowest rate, efficacious program in fields lacking glyphosate-resistant weeds. Such increases, moreover, could lead to new or more serious environmental problems and herbicide-triggered public health impacts, for reasons set forth in Chapter V.

Impacts of Farm Income

In the U.S., corn farmers paid $60 to $70 for a bag of corn seed in the 1980s, and $77.70 in 1996, the year the first GE corn hybrid was sold. The price of GE corn seed varieties doubled over the first decade of use (1996-2005), and today is around $260 – more than three-fold the cost in the pre-GE corn era. Detailed information on the rising costs of GE seed, all based on USDA data, is presented in Chapter V, section C.

Conventional corn seed purchased in 2010 accounted for about 11% of gross farm income, while SmartStax corn from Monsanto and Dow AgroSciences, expressing eight distinct GE traits, cost some farmers over $320 per bag and accounted for about 23% of gross income per ha that year.

Soybean seed was selling for around $14.80 per bushel in 1996 when the first RR soybeans were marketed. Today, RR soya seed costs around $53.20, raising farmer seed costs more than three-fold.

In the 25 years from 1975 through 2000, soybean seed prices rose a modest 63%. Over the next ten years, as RR soybeans came to dominate the market, the price rose an additional 230%.

By any measure, the steeply upward trajectory in the price of GE seeds since 1996 in the U.S. has cut deeply into average net farm income. From 1975 through 1997, soya farmers spent 4% to 8% of gross income from the market on purchased seed. In 2008-2010, soya farmers in the U.S. harvested relatively high yields and enjoyed historically high market prices, yet still spent 13% of their gross market income on seed – about twice the historic norm.

Maize growers in the U.S. spent 4% to 11% of gross market income per ha on seed from 1975 through the beginning of the GE crop era in 1996, and 12% to 15% of operating costs per ha. Since 1996, the price of conventional seed has risen just marginally above historic levels as a percent of gross income and operating expenses.

GE maize seed, on the other hand, has become much more expensive as a percent of gross market income. In 2010, GE corn seed accounted for 18% of gross market income per ha, over twice the historic norm.

If these GE seed price trends continue, the consequences for American farmers will be of historic significance, especially when market prices drop from recent, unprecedented levels. Sufficient dollars once earned and retained by farmers will be transferred to the biotechnology-seed-pesticide industry. As net farm income falls, less money will be available for investing in the sustainability of America's farms and farm families. As biotech-seed industry profits continue to rise, so too will the industry's ability to drive innovation in directions favorable to them.

Sharply higher GE seed prices have been justified, in part, by reduced expenditures on herbicides other than glyphosate and the convenience and simplicity of the RR system. With historically high crop prices since 2007, U.S. farmers have been able to absorb the rising costs of GE technology. But resistant weeds have, and will continue to drive weed-management costs upward. If higher herbicide and seed costs are coupled with an even partial return to historic crop price levels, farmers could face tenuous economic conditions, generating losses on a substantial portion of operations. Farmers in the EU are likely to face the same sort of economic pressures if RR crops are approved and widely adopted.

Wild Cards

Glyphosate has been regarded as a relatively safe herbicide for almost four decades. But dramatic increases in use worldwide have led to higher levels of contamination in air and water, and much more collateral damage near some sprayed fields, particularly in South America where soya fields often stop right at the edge of villages.

Evidence of new exposure pathways and sometimes markedly higher exposure levels are stimulating new research on the toxicological properties and impacts of Roundup herbicides (for details, see Chapter V). Some formulations have been implicated in cell damage and adverse reproductive impacts, leading manufactures to seek out alternative adjuvants and surfactants (chemicals used to formulate pesticide products that improve flowability, as well as the ability of a herbicide to adhere to the surface of weeds). Impacts on biodiversity in and around crop fields are known to alter both insect and bird populations and interactions. The possible impacts on farm animals heavily reliant on RR maize silage deserve a much closer look, as do human exposures.

As scientists and regulators work to resolve lingering and new questions over the safety of glyphosate, they will also be challenged to better understand and manage the risks inherent in the older herbicides likely to be brought back into service to deal with glyphosate-resistant weeds. Three are among the riskiest herbicides still in widespread use (2,4-D, dicamba, and paraquat).

It is hard to predict the consequences of new, EU-wide policies that call for the promotion of prevention-based Integrated Pest Management (IPM) systems in order to reduce reliance on higher-risk herbicides.

One provision of the new "Sustainable Use of Pesticides" Directive states, in effect, that any pest management practice or input that increases the risk of resistance is not compatible with IPM. Clearly, RR technology fundamentally violates this provision, especially when heavily relied upon.

Despite strong evidence confirming the importance of herbicide-resistant weed management, it remains to be seen whether and how EU regulators, farmers, weed scientists, and the industry will strive to prevent resistance. There is widespread agreement on the primary tactics and strategies to prevent herbicide resistance, yet government agencies worldwide lack tools to compel adherence to them. At the present time, the primary industry response to the spread of resistant weeds in the U.S. has been developing crops tolerant to multiple herbicides, an approach likely to make matters worse.

"It is clear to most weed scientists who are involved in herbicide research, and even those who are not, that the best way to reduce selection pressure for herbicide resistance is to minimize herbicide use. However, the 'solutions' that have emerged in most recent [U.S.] meetings on herbicide resistance have usually involved more herbicide use."

"Our View," *Weed Science*, 2012 (Harker et al.)

II. Why This Report?

When grown by experienced farmers, crops usually thrive in the presence of fertile soil, water, and sun. But so do weeds. This is why weeds have always been, worldwide, the most common, ubiquitous and serious pest problem confronting farmers. It is also why the cost, effectiveness and environmental impacts of weed management play such a big role in determining the success, and acceptability, of farming systems and technology.

Genetic engineering made possible the introduction of revolutionary, herbicide-based weed management technology in 1996. By inserting a gene from a flower into soya, cotton and corn breeding lines, the seed-biotech industry created plants not susceptible to the herbicide glyphosate (marketed by Monsanto as Roundup). Crop varieties containing this gene came to be known and marketed as Roundup Ready (RR).

Iowa State University weed scientist Michael Owen calls Roundup Ready technology "…the most important change in technology in the history of agriculture" (Owen 2011). University of Mississippi weed scientist Stephen Duke has highlighted the rapid pace of adoption, which he calls "the most rapid…in the history of agriculture" (Duke 2011).

Roundup Ready (RR) technology was revolutionary because it made it possible for farmers to apply a single herbicide effective against virtually all grass and broadleaf weeds. This greatly simplified weed management systems, which in the mid-1990s were complex and unforgiving because they required relatively precise combinations of products, accurate rates of application, and the correct timing of applications in order to achieve good results and avoid damage to the crop and/or nearby vegetation.

In addition, weed management in the mid-1990s in the U.S. was costly and slipping in effectiveness largely because of the emergence of resistance to several widely used products. But with RR technology, an American farmer could plant the crop, spray the field once a week or two later with a single, easy to handle herbicide, glyphosate, and start planning harvest.

If late-germinating weeds emerged and threatened crop yields, or if an untimely rain shower soon after a Roundup application washed the herbicide off growing weeds, rendering it ineffective, the farmer could simply make another application a few days or week later.

Drawing on the experience of farmers in the U.S., this report projects the likely impacts of RR maize, soya, and sugar beets on herbicide use across the EU's 27 member states, assuming these GE technologies are approved for planting. The key measures of herbicide use for each of the three crops are the total kilotonnes (kt) applied, and the average kilograms per hectare of total herbicides, glyphosate, and herbicides other than glyphosate.

While oilseed rape is a common crop in the EU, and there are GE, herbicide-tolerant oilseed rape cultivars in use in other countries, none are approved for cultivation in the EU.

A. The Three Scenarios

Three scenarios are modeled through 2025, starting from baseline estimates of herbicide use in 2011. This 15-year period corresponds roughly in length to the 16 years of experience with herbicide-resistant (HR) corn, soya, and cotton in the U.S. While this analysis is based on EU approval by, and first commercial use in 2012, the results are likely to reflect the first 15 years of RR crop adoption in the EU starting in 2014, or 2016.

The scenarios reflect plausible trajectories in the use of herbicide-tolerant technology, and were chosen to highlight the possible consequences of whether and how the EU, its member nations, and EU farmers decide to utilize HT technology.

"**Scenario 1 – No Genetically Engineered (GE) Crops**" projects likely trends in herbicide use in the absence of approval or commercial planting of RR or other HT crops in the EU.

The first scenario is based on the assumption that the EU chooses to bypass this first-generation of HT traits, at least through 2025. Widely discussed reasons advanced in support of this outcome include a lack of perceived need, concern among farmers over the cost of the technology, worry over the emergence of resistance, consumer concerns over the adequacy of GE crop safety assessments, limits on access to value-added, non-GE markets, and loss of control over genetics, agronomic and weed management decisions.

"**Scenario 2 – Unlimited Adoption**" assumes that farmers in the EU adopt newly marketed RR crops as enthusiastically as farmers in the U.S. In this scenario, changes in the hectares planted to RR versus conventional varieties, and in the hectares sprayed with glyphosate, track trends in the U.S from 1996 through 2011.

The second scenario is based on the assumption that the EU and its member nations approve RR technology without any restrictions, and that the technology is incorporated in essentially all varieties of maize, soya, and sugar beets. In the early years of adoption, some farmers wanting to purchase RR seeds might not be able to get them, but as the RR share of the seed supply increases, some farmers wanting to plant non-GE or not-RR varieties might not be able to find suitable genetics without the RR gene.

“**Scenario 3 – Targeted Adoption**” assumes targeted adoption of RR technology, coupled with a strong commitment to recommended weed resistance-management practices.

The third scenario envisions a middle course of action, whereby approval for planting RR varieties is granted, but only in conjunction with a set of mandatory and enforceable limitations on how frequently and widely the technology can be used. Such provisions would be designed to assure adherence to weed resistance-management recommendations, including a prohibition against planting RR crops two years in a row on any given field.

Preventing Weed Resistance

There are two universally accepted herbicide resistant-management strategies –

- Embrace the “many little hammers” approach by diversifying the tools, tactics, and practices used against weeds over time and space (Liebman & Gallandt 1996), and
- To the extent chemical herbicides are relied on, rotate the selection of herbicides to include different modes of action, and avoid the recurrent use of a single herbicide on the same yield, year after year.

Compliance with the second strategy means that a farmer could not plant a field to RR crops in back-to-back years. It also means that on fields where farmers made a pre-plant or late season application of glyphosate on non-RR crops, the farmer would not be allowed to plant a RR cultivar in the same field in the next season.

The practical impact of such provisions for farmers would be to limit the maximum percent of hectares planted to RR crops to 50%. Or, a farmer could plant 100% RR crops one year and none the next.

Scenario 3 envisions the targeting of RR hectares to those fields with the most severe weed management problems, and no back-to-back panting of RR crops. While conceptually straightforward, regulatory authorities in the EU and U.S. have few tools and limited authority to cap the adoption of an agricultural technology, once approved for commercial use.

One model exists for imposing such restrictions. As a condition of initial approval for *Bt* corn and cotton, and to prevent resistance in target insects, the U.S. Environmental Protection Agency (EPA) imposed mandatory refuge requirements via enforceable provisions on the labels of *Bt* corn and cottonseed bags. In the early years of adoption, farmers were required to plant 20% to 25% of their corn and cotton fields to cultivars lacking the *Bt* gene, in the hope that any insects that evolve resistance from feeding on the plants in the *Bt* portion of fields would mate with susceptible insects living in and feeding on the refuge hectares, resulting in progeny that is still susceptible to *Bt.*

Regulators could insist that a similar provision be crafted that requires adherence to herbicide resistance-management practices. A program to monitor compliance would also need to be created, and again can be modeled after the initially successful resistance monitoring and management program the EPA developed in cooperation with growers and the biotechnology-seed industry in the case of *Bt* corn and cotton.

But again, lessons learned in the U.S. should be heeded. Farmer compliance with mandatory *Bt* corn refuge requirements in the U.S. has slipped to only 59% in 2011 (Kaskey 2012). Over the years, pressure from the biotech-seed industry, coupled with the trend toward stacking multiple *Bt* genes in the same variety, has resulted in a substantial weakening of resistance-management requirements (Tabashnik & Gould 2012).

As a result of spotty compliance with weakened rules, several resistant populations of insects targeted by *Bt* corn and cotton have now been confirmed in multiple states. Most worrisome is the finding that "…western corn rootworm (*Diabrotica virgifera virgifera)* has rapidly evolved resistance to Cry 3Bb1 corn in the laboratory, greenhouse, and field" (Tabashnik & Gould 2012). The drift away from strict adherence to resistance-management requirements, and over-confidence in their effectiveness, led Dr. Bruce Tabashnik and Dr. Fred Gould to call for a return to much larger refuge areas – 50% in the case of single *Bt* corn varieties, and 20% in the case of dual or triple *Bt* varieties.

B. Impact of the EU's "Sustainable Use of Pesticides" Directive

Directive 2009/128/EC describes a "framework for Community action to achieve the sustainable use of pesticides," and was adopted October 21, 2009. Paragraph (5) calls upon member nations to develop "National Action Plans" that include quantitative targets for reduced reliance on relatively high-risk pesticides, and for the adoption of IPM and other "alternative approaches or techniques…" to reduce pesticide use.

Paragraph (18) calls for member states to "establish the necessary conditions and measures for its [IPM] implementation." Paragraph (19) goes on to say "implementation of the principles of integrated pest management is obligatory…" (EU Parliament 2009).

Progress toward reducing pesticide risks must be monitored via "harmonized risk indicators that will be established at the Community level" (EU Parliament 2009, para. 20). Member states "should determine penalties applicable to infringements of national provisions adopted pursuant to this Directive and ensure that they are implemented… [and are] effective, proportionate, and dissuasive" (EU Parliament 2009, para. 21).

Other provisions "generally prohibit" aerial spraying and call for special attention to protect aquatic environments through, among other things, establishment of no-spray buffer areas. Pesticide use should be "minimized or prohibited in certain specific areas" like schoolyards and playgrounds, or close to healthcare facilities (EU Parliament 2009, article 12).

Member states are required to submit their national plans to the Commission by December 14, 2012. Two years later, the Commission will submit a report to the European Parliament on the best ways to set "targets to reduce the risks and use of pesticides." By June 30, 2013, member states are required to report to the Commission on steps taken to create "the necessary conditions for the implementation of integrated pest management" (EU Parliament 2009, Article 14, #2), which should include "appropriate incentives to encourage professional users to implement crop or sector-specific guidelines for integrated pest management" (EU Parliament 2009, #5).

The "General principles of integrated pest management" set forth in the Directive's Annex III emphasize the prevention and/or suppression of pests via a combination of tactics including crop rotation, cultivation, the planting of resistant cultivars, the planting of clean seed and transplants, and the protection and enhancement of beneficial organisms.

The likelihood of EU approval and widespread planting of GE-HT maize, soya, and sugar beets will be influenced, if not determined, by whether GE-HT technology is deemed compatible with IPM. The sixth item in Annex III states –

> "The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary…and they [applied pesticides] do not increase the risk for development of resistant populations of harmful organisms."

Clearly, when farmers pay the extra money for herbicide-tolerant seeds, they are going to capitalize on their investment by spraying the associated herbicide or herbicides. This has clearly been the case in the U.S., and indeed all other countries where substantial areas have been planted to HT varieties. Hence, HT technology essentially assures that at least one, and often two or three applications of a single active ingredient will be made in a production season. This, of course, enhances selection pressure on weed populations and increases the risk of resistance, especially when a crop rotation includes two crops engineered to tolerate the same herbicide, like RR maize and RR soya.

For these reasons, it is hard to imagine that the EU Commission will deem HT crops compatible with IPM as currently defined, and hence implementation of this directive would appear to rule out the repeated planting of HT crops as done in the U.S., and as modeled in Scenario 2. Instead, it is more likely that EU farmers will be more selective in deciding where HT-RR crops are planted and will, furthermore, follow mandatory resistance-management practices. This is the pattern of adoption that Scenario 3 represents.

C. Trends in Herbicide Use Rates

In response to pressure from regulators and environmental groups, the pesticide industry has invested heavily over the last three decades in the discovery of more potent active ingredients effective at progressively lower rates of application. In both the U.S. and EU, they have been quite successful in this quest.

For example, 27% of soya hectares in the U.S. in 1996 were treated with pendimethalin at an average rate of 1.1 kg/ha and another 22% were sprayed with trifluralin at a rate of 0.99 kg/ha (NASS 1997). By 2002 the combined percentage of soya hectares treated with these two high-dose herbicides had dropped from 49% to 16% (NASS 2003), and just 5% were treated in 2006 (NASS 2007).

The number of registered soya herbicides applied at rates below 0.11 kg/ha increased from nine to 17 between 1996 and 2006. The market leader in 1996, imazethapyr, was applied to 43% of hectares planted at a rate of 0.07 kg/ha (NASS 1997). As a result, the amounts of herbicides applied to conventional, not-RR soya crops have steadily fallen for over a decade (Benbrook 2012; Benbrook 2009a). In contrast, glyphosate is a relatively high-dose herbicide that is usually applied at a rate between 0.7 to 0.9 kg/ha.

In the case of U.S. maize production, the average rate of application for herbicides applied, other than glyphosate, has fallen from 1.28 kg/ha in 1996 to 0.84 kg/ha in 2010, a 34% decline. There were seven herbicides applied at rates below 0.11 kg/ha on the market in 1996, and 20 in 2010 (NASS 1997 and 2011).

The trend toward lower-dose herbicide chemistry seems likely to continue for the foreseeable future. Greater reliance on herbicides targeting specific weeds also seems likely, leading to probable increases in the average number of different active ingredients applied on a given hectare of cropland. These well-established trends have been taken into account in the projections embedded in the three scenarios.

III. A Method for Projecting Changes in Herbicide Use

Six steps are required to project the impact on herbicide use of adoption of Roundup Ready (RR) maize, soya, and sugar beets in each of the 27-member countries of the European Union (EU) across the three scenarios. In brief, these steps are –

1. The hectares planted to each of these three crops, in each country, must be determined in the baseline year, 2011, and then projected through 2025.
2. Changes in the percent of hectares planted to RR varieties, and as a result, changes in the percent of hectares treated with glyphosate must be projected through 2025.
3. Increases in the average rate of glyphosate applications per crop year must be projected through 2025. This key parameter, glyphosate "Rate per Crop Year," takes into account both the average number of applications, as well as the average rate of application each time a field is sprayed.
4. Changes in the number of applications with herbicides other than glyphosate, including both the average number of herbicides applied, as well as the average "Rate per Crop Year" across all non-glyphosate herbicides applied.
5. Total herbicide use in each crop-country-year combination is calculated as the sum of glyphosate use and "Other Herbicide" use.
6. Herbicide use results are then aggregated by crop across the 27-EU member nations, and combined across the three crops, to produce the final estimates of the impacts of the three scenarios on changes in herbicide use from the 2011 baseline level to 2025.

A. Cropland Area and Hectares Planted

Data were obtained from Eurostat on total cropland area, and the hectares planted each year to various crops and crop types – cereals/grains (including grain maize), dried pulses/legumes, root crops (sugar beets), industrial crops (soya), fodder (maize fodder [silage, green chop]), vegetables, and fruit. Total hectares planted to maize are the sum of hectares planted to grain and fodder maize.

Information on total cropland area and all major crops was transferred into an Excel workbook and used to develop the country and crop-specific baselines and projections through 2025. Data on cropland area from 1996 through 2011 were used to calculate the percent change in maize, soya, and sugar beet hectares planted over this 14-year period, as well as changes in total cropland area through 2025.

The percent change in hectares planted to the three crops from 1996 through 2011 was used to estimate the average annual change in hectares planted, and to determine the trend in hectares planted in from 2006-2011. These data were then used to project changes in the hectares planted to each crop in each EU country.

In some cases, there have been substantial increases or decreases in the hectares planted to a particular crop in a given country, leading to large average annual changes (as high as 10%). This problem is especially acute in country-crop combinations where only a few thousand hectares are planted, because the planting of a few thousand more or fewer hectares might then account for a large percentage change.

Accordingly, the change in hectares planted to a specific crop from 2011 to 2025 in each EU member nation was limited to +/- 20% of the 2011 base. In addition, limits were placed on the increase in the share of total cropland area accounted for by the three crops. In no event does the share increase by more than 10%.

In all cases, the total cropland area in each EU country was assumed to remain stable from 2017 through 2025.

Projecting land and herbicide use data for three crops in 27 countries is a major undertaking. To make it more manageable, one or more "index" countries were identified for each of the three crops in the three EU zones – Zone A North; B Central, and C South.

An index-country approach is used in establishing baselines and when making projections of herbicide use. In several countries in each region, few or no hectares of maize, soya, and/or sugar beets are grown, and so very little data are available on herbicide use. In such cases, data from a nearby index country were used instead.

Table 3.1 presents the matrix of EU zones and index countries for the three crops included in the present analysis. An "X" identifies an index country within a given region, for which a source was found for herbicide use data. It also shows the State in the U.S. that the index country is matched with for purposes of projecting trends in the adoption of RR technology by maize and soya farmers, as well as changes in the use of glyphosate and "Other Herbicides."

Table 3.2 reports the index-country share of total EU hectares planted to each of the three crops. In the case of maize (grain + fodder)and soya, index countries account for 61% of total EU hectares planted in 2011. Sugar beet index countries account for only 36% of the hectares planted across the EU, reflecting the fact that sugar beets are spread more evenly across the EU than maize and soya production.

Table 3.1 European Union (EU) Index Countries by Zone and Crop and Matching U.S. States Used in Modeling the HT Crop Adoption Trajectory and Herbicide Use Patterns Across the Three Scenarios

	Index Country in EU			Matching U.S. State		
	Maize	**Soya**	**Sugar Beets**	**Maize**	**Soya**	**Sugar Beets**
EU Zone A - North						
Denmark	UK	Italy	UK	Michigan	Iowa	Minnesota
Estonia	UK	Romania	UK	Michigan	Wisconsin	Minnesota
Finland	UK	Italy	UK	Michigan	Iowa	Minnesota
Latvia	UK	Romania	UK	Michigan	Wisconsin	Minnesota
Lithuania	UK	Romania	UK	Michigan	Wisconsin	Minnesota
Sweden	UK	Italy	UK	Michigan	Iowa	Minnesota
EU Zone B - Central						
Austria	France	Italy	Germany	Wisconsin	Iowa	Minnesota
Belgium	Germany	Italy	Netherlands	Minnesota	Iowa	Minnesota
Czech Republic	Germany	Romania	Germany	Minnesota	Wisconsin	Minnesota
Germany	X	Italy	X	Minnesota	Iowa	Minnesota
Hungary	Romania	Romania	Germany	Minnesota	Wisconsin	Minnesota
Ireland	UK	Italy	UK	Michigan	Iowa	Minnesota
Luxembourg	Germany	Italy	Germany	Minnesota	Iowa	Minnesota
Netherlands	X	Italy	X	Michigan	Iowa	Minnesota
Poland	Germany	Romania	Germany	Minnesota	Wisconsin	Minnesota
Romania	X	X	Germany	Minnesota	Wisconsin	Minnesota
Slovakia	Germany	Romania	Germany	Minnesota	Wisconsin	Minnesota
Slovenia	Romania	Romania	Germany	Minnesota	Wisconsin	Minnesota
United Kingdom	Index	Italy	X	Michigan	Iowa	Minnesota
EU Zone C - South						
Bulgaria	Romania	Romania	Germany	Minnesota	Wisconsin	Minnesota
Cyprus	Spain	Italy	Germany	Iowa	Iowa	Minnesota
France	X	Italy	Netherlands	Wisconsin	Iowa	Minnesota
Greece	Spain	Italy	Germany	Iowa	Iowa	Minnesota
Italy	Spain	X	Germany	Iowa	Iowa	Minnesota
Malta	Spain	Italy	Germany	Iowa	Iowa	Minnesota
Portugal	Spain	Italy	Germany	Iowa	Iowa	Minnesota
Spain	X	Italy	Germany	Iowa	Iowa	Minnesota

B. Establishing Herbicide Use Baselines

Unlike the U.S., pesticide use data are sparse for several EU countries. The main exceptions are the U.K., Netherlands, and Germany, and to a lesser extent Romania and Spain. This may soon change, as Eurostat is conducting a more comprehensive survey of pesticide use across member nations to facilitate implementation of the "Sustainable Use of Pesticides" Directive (Directive 2009/128/EC). The Directive explains that the survey will be drawn upon in establishing consistent herbicide use baselines across the EU, from which reductions in use can be monitored over time.

Several teams of government, academic, and industry scientists have compiled herbicide use data sets from various sources and published peer reviewed research articles reporting representative herbicide use patterns (Bennet et al. 2004; Brookes 2003; Devos et al. 2008; Dewar 2003; Dickeduisberg etal. 2012; Meissle et al. 2010; RIVM 2012; Vasal et al. 2012).

Table 3.2 Hectares of Maize (grain + fodder), Soya, and Sugar Beets Grown in Index Countries in 2011 and Share of EU Total Hectares Planted

	Hectares Planted 2011	**Percent of EU-Wide Hectares Planted in 2011**
Maize - Germany	2,516,700	17%
Maize - U.K.	153,000	1%
Maize - France	2,974,212	20%
Maize - Romania	2,647,332	18%
Maize - Spain	400,000	3%
Maize - Netherlands	251,741	2%
Total Maize Index Countries	8,942,985	61%
Total EU	14,641,405	
Soya - Italy	165,955	42%
Soya - Romania	73,819	19%
Total Soya Index Countries	239,774	61%
Total EU	392,257	
Sugar beets - Germany	398,100	24%
Sugar beets - Netherlands	73,329	4%
Sugar beets - United Kingdom	113,000	7%
Total Sugar beets Index Countries	584,429	36%
Total EU	1,637,726	
Three Crop Totals	16,671,388	16.2%

Source: Data on crop hectares grown are from Eurostat.

In most such cases, proprietary industry sales and/or survey data have been drawn upon in specifying typical herbicide use rates and the percent of hectares treated. In addition, government ministries in some EU countries have periodically compiled data and were kind enough to make it available to the project team (e.g. the NEPTUN survey of pesticides applied in the German sugar beet industry, Vasal et al. 2012; RIVM 2012). Last, the biotech-seed industry has commissioned several academic and consultant reports on the impacts of adoption of herbicide-tolerant technology in the EU (e.g. Dewar 2009). Some contain otherwise hard-to-get industry data on contemporary herbicide use patterns.

Herbicide use baselines and projections were done for each index country-crop combination, and then used as the foundation for baselines and projections in other, non-index countries in the same EU zone (see Table 3.1 above).

In general, the data available to establish year 2011 herbicide baselines in index countries were most complete in the case of maize and soya, where index countries account for 61% of hectares planted across the EU that year, followed by sugar beets (36% hectares planted across the EU).

Each herbicide use baseline for a given index crop-country combination in 2011 is composed of three key data elements:

1. Glyphosate -- The percent of hectares treated with glyphosate, the rate of glyphosate applied per crop year, and total glyphosate (Roundup) kg applied in 2011.

2. "Other Herbicides" (i.e., other than glyphosate) – the number of "Other Herbicides" applied on the average hectare, the average rate per crop year of these other herbicides, and total kg of "Other Herbicides" applied.

3. Total Herbicide Applied – the average number of all herbicide active ingredients applied per hectare, the average rate per crop year, and total kg applied (simply the sum of glyphosate and other herbicides applied).

As an example, Table 3.3 presents the calculation of the maize herbicide use baseline for Germany. Note that 2,516,700 ha of maize (grain + fodder) were planted in 2011 (from Eurostat). Herbicides are broken into pre-emergence and post-emergence, and a total of 15 products were applied. In reality, more herbicides were used in maize production in Germany. Several active ingredients not listed in Table 3.3 fall in the same family of chemistry as another herbicide in the baseline table. Herbicides within a family of chemistry typically control a similar compliment of weeds, and have comparable physical, chemical, and environmental fate properties.

Some of the 55% of hectares treated with s-metolachlor were likely treated with acetochlor, and some of the 73% hectares treated with the two sulfonylurea herbicides in Table 3.3 (nicosulfuron and rimsulfuron) were likely sprayed with other herbicides in this large family of chemistry. Several pre-mix products contain either s-metolachlor or acetochlor in conjunction with another herbicide, such as terbuthylazine, while other pre-mix herbicides contain one or more sulfonylurea active ingredients, along with one or two other herbicides.

While details regarding the exact volumes of different active ingredients matter greatly to herbicide manufacturers, to the farmer and environment, there is typically little difference in impacts across multiple, closely related products. Hence, inability to distinguish exactly which product is being used has little bearing on this report's findings.

For single active ingredients, "Percent Hectares Treated" reflects the portion of the 2.5 million hectares of maize grown in Germany in 2011 that were sprayed with that active ingredient one or more times. Across all herbicides applied, the sum of "Percent Hectares Treated" equals the average number of distinct herbicides applied one or more times on each hectare of maize. Note in Table 3.3 that maize farmers in Germany applied an average 4.02 herbicides per hectare of maize, one or more times. The kilograms associated with a second, third, fourth, or more applications of a given active ingredient are captured in the parameter "Rate per Crop Year."

Table 3.3 Germany Maize Herbicide Use 2011 Baseline

	Percent Hectares Treated	Hectares Treated	Rate per Crop Year (grams a.i./ha)	Kilograms Applied (Calculated)
Summary Data				
Glyphosate	27%	679,509	1,000	679,509
Other Herbicides	375%	9,430,075	434.2	4,094,772
Total Herbicides	402%	10,109,584	472.3	4,774,281
Details by Active Ingredient				
Pre-emergence				
S-metolachlor	55%	1,384,185	1,000	1,384,185
Terbuthylazine	52%	1,308,684	666	871,584
Flufenacet	3.7%	93,118	500	46,559
Glyphosate	27%	679,509	1,000	679,509
Metosulam	4%	100,668	20	2,013
Pendimethalin	4%	100,668	800	80,534
Dimethenamide-p	25%	629,175	850	534,799
Post-emergence				
2,4-D	2%	50,334	440	22,147
Dicamba	6%	151,002	202	30,502
Mesotrione	58%	1,459,686	75	109,476
Bromoxynil	38%	956,346	300	286,904
Bentazone	8%	201,336	500	100,668
Rimsulfuron/ Nicosulfuron	73%	1,837,191	30	55,116
Terbuthylazine	45%	1,132,515	500	566,258
Fluroxypur	1.0%	25,167	160	4,027
Totals	**402%**	**10,109,584**		**4,774,281**

Notes: Surveyed hectares planted were 2,516,700. The "Rate per Crop Year" takes into account both the number of applications and one-time rate of application. For most herbicide active ingredients, the one-time rate of application is marginally lower than reported in the "Rate per Crop Year" column.

Source: Devos et al. (2008) and Dewar (2009), with updated glyphosate data from Dickeduisberg et al. (2012).

In Table 3.3, and all other crop-country baseline tables, the top three rows of data capture the major data elements used in the projections. The data appearing below these three lines form the basis for the major data elements.

As evident in Table 3.3, the most widely applied herbicide was a sulfonylurea (rimsulfuron or nicosulfuron), reaching 73% of hectares planted. Fluroxypur was the least frequently applied, at just 1% of hectares treated.

Reasonably complete data for 2007 were available on the hectares treated with different herbicides in Germany from a peer-reviewed paper in the journal *Pest Management Science* (Dewar 2009). Dewar's analysis was funded by a grant from Monsanto Europe SA, Brussels. In addition, Dewar was granted access to proprietary herbicide use data on several EU countries compiled by the Kleffman Group, a leading global agribusiness-consulting firm.

Dewar (2009) lists the hectares treated with herbicides within 16 families of chemistry, and in Dewar Tables 2a and 2b, the major active ingredients applied within each family of chemistry are listed. These three tables were used to develop the list of herbicides applied on maize in Germany in the 2011 baseline (Table 3.3), as well as estimate the total number of hectares treated.

Typical "Rates [of Application] per Crop Year" were derived from a review of allowed label rates and a study by Devos et al. (2008) that analyzed the possible impact of herbicide-tolerant maize in Belgium. Devos et al. application rate data were derived from government sources and via expert consultations; the impacts of HT maize on herbicide use were simulated. The percent hectares treated data from Dewar (2008) and application rate data in the Devos et al. (2008) study were cross-checked for general accuracy against other EU data sources, product labels, and U.S. application rates.

More recent data on glyphosate use in Germany (Dickeduisberg et al. 2012) indicated a need to adjust the percent of maize hectares treated upward to 27% in the 2011 baseline. The glyphosate rate was also increased from 0.9 kg/ha to 1.0 kg/ha, closer to the 1.08 kg/ha rate reported by the U.K. (Garthwaite et al. 2012) and the Netherlands agricultural ministries in 2010-2011 (RIVM 2012).

As shown in Table 3.3, a total of 4.1 kt of "Other Herbicides" were applied on maize in Germany in 2011, and 679,509 kg of glyphosate was used. A total of 10.1 million ha were treated with a distinct active ingredient in 2011 one or more times.

Six data elements in the upper portion of Table 3.3 form the 2011 baseline used in making projections through 2025. They include the three values in the column "Percent Hectares Treated" and the three values in the "Rate per Crop Year" column.

Across index country and crop combinations, there was considerable variability in the data available to establish baselines. In several cases, total quantities applied were known, but average "Rates per Crop Year" had to be established from secondary sources in order to calculate "Percent Hectares Treated." In other cases, information was available on how many products had been applied, and/or average kilograms applied, but limited information was available on rates or percent of hectares treated.

Cases with limited data were addressed through use of the following basic formula that can be used to calculate the kilograms of a pesticide applied on any given crop in a given year:

Kilograms Herbicide_x = (% Hectares Planted Treated with Herbicide_x) x (Hectares Planted Crop Y) x (Rate per Crop Year Herbicide_x)

There are four variables in the above equation. In all cases, one variable was always accessible – "Hectares Planted." In general, "Rate per Crop Year" can be estimated based on data in the literature or from other countries, or information on herbicide labels. To complete the baseline for a given country-crop combination, one additional dataset is needed – either hectares treated (or percent of hectares treated), or total kilograms applied. The other variable can then be easily calculated using the above formula.

C. Projecting Herbicide Use through 2025 Under Three Scenarios

Projections of changes in herbicide use in the event of EU approval of herbicide-tolerant maize, soya, and sugar beets were made under three scenarios. The scenarios were designed to provide insights into the likely consequences if HT technology is approved and marketed EU-wide.

The first scenario assumes that the EU does not approve current generation, or any other herbicide-resistant crops, and reflects a continuation of the conventional weed management status quo through 2025. Herbicide use levels in this scenario will be compared to the other two scenarios, to estimate the impact of GE-HT technology in the EU.

Scenario 2 models unrestricted approval and widespread adoption of RR, glyphosate-resistant maize, soya, and sugar beets. The timing and extent of adoption is assumed to reflect the trajectory of adoption in the U.S. from 1996 through 2011.

Scenario 3 is based on targeted adoption, coupled with mandatory resistance-management practices. It represents a pace of adoption, and likely patterns of herbicide use, that would come about if EU regulatory decision-makers and farmers choose to make a concerted effort to prevent the emergence and spread of glyphosate-resistant weeds.

Changes in four herbicide-use parameters from 2012 through 2025 are estimated in each of the three scenarios –

- Percent hectares of maize, soya, and sugar beets treated with glyphosate;
- Percent hectares treated with a distinct herbicide active ingredient other than glyphosate ("Other Herbicides");
- Average rate of application per crop year of glyphosate active ingredient, taking into account both the average one-time rate of application and the average number of applications; and
- Average rate of application per crop year of "Other Herbicides."

These parameters, coupled with the hectares planted each year to the three GE-RR crops studied herein, make it possible to project the kilograms of herbicides applied from 2012 through 2025, based on the three scenarios outlined above.

Changes in the above four parameters from the 2011 baseline through 2025 are based on the comparable changes in the U.S. as American farmers adopted RR technology during the 1996-2011 period. Each index country noted in Table 3.1 is matched with a state in the U.S. that has, to the extent possible, roughly similar soils and climatic conditions. Then, data from the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) were used to approximate the overall change in percent of hectares treated with glyphosate from 1996 to 2011, changes in the glyphosate rate per crop year, and corresponding impacts on the use of other herbicides in terms of percent hectares treated and average kg/ha applied.

The primary differences between scenarios 2 (Unlimited Adoption) and 3 (Targeted Adoption) arise from mandatory herbicide resistance-management provisions including, in particular, a prohibition from planting the same hectare to RR crop two years in succession. Such a requirement would cap the rate of adoption and restrict the hectares treated with glyphosate to about one-half the levels in scenario 2. As a result of such a limit on use, it is assumed that EU farmers will strategically target fields with relatively dense or hard to control weeds for planting with RR varieties.

A model was developed using Microsoft Excel that combines projections of changes in the four herbicide-use parameters by year from 2012 through 2025, with the hectares likely to be planted to each of the three crops, by year. Herbicide use under the three scenarios has been calculated by year and the results are summarized by crop, and across the three crops in Chapter 6.

Table 3.4 presents the projections of herbicide use in maize production in Germany from the 2011 baseline through 2025, for all odd years. The first line of data reports the hectares likely to be planted to maize. In each of the three scenarios, the variable "Percent Hectares Treated" is multiplied by the hectares planted that year to project hectares treated. The variable "Rate per Crop Year" is expressed in kg/ha; the value in each column is used in projecting the total kilograms applied in that year for glyphosate, other herbicides, and total herbicides. The three rows of data in each scenario covering "kg Active Ingredient" are calculated for a given year using the formula:

kg herbicide applied = (% Hectares treated) x (Hectares planted) x (Rate per crop year)

As evident in Table 3.4 under scenario 2, total herbicide use by German maize farmers is projected to rise to 7.9 kt in 2025, from 4.8 kt in 2011. Glyphosate is projected to account for 4.6 kt of total use in 2025, or 58% of total use, up from 14% in 2011.

Table 3.4 Germany Maize Herbicide Use Projections Under Three Scenarios

	2011 Baseline	2013	2015	2017	2019	2021	2023	2025
Hectares Planted	2,516,700	2,698,494	2,811,368	2,900,839	2,963,542	3,027,002	3,030,333	3,033,061
Scenario 1: No GE Crops								
Percent Hectares Treated								
Glyphosate	27%	27.2%	27.5%	27.7%	27.9%	28.2%	28.4%	29%
Other Herbicides	375%	369.3%	364.0%	358.6%	353.3%	347.9%	342.6%	337%
Total Herbicides	402%	396.6%	391.5%	386.3%	381.2%	376.1%	371%	366%
Rate per Crop Year (kg/ha)								
Glyphosate	1.00	1.01	1.03	1.04	1.06	1.07	1.09	1.10
Other Herbicides	0.43	0.43	0.42	0.41	0.41	0.40	0.39	0.39
Total Herbicides	0.47	0.47	0.46	0.46	0.45	0.45	0.45	0.44
kg Active Ingredient								
Glyphosate	679,509	745,336	794,142	837,797	874,881	913,197	934,005	954,868
Other Herbicides	4,094,772	4,259,827	4,303,864	4,304,537	4,260,505	4,213,936	4,082,834	3,952,864
Total Herbicides	4,774,281	5,005,164	5,098,005	5,1142,334	5,135,386	5,127,133	5,016,839	4,907,732
Scenario 2: Unlimited Adoption								
Percent Hectares Treated								
Glyphosate	27%	31%	35%	49.0%	63%	75%	85%	95%
Other Herbicides	375%	362.4%	350%	330%	310%	293.2%	279.6%	266%
Total Herbicides	402%	393%	385%	379%	373%	368%	365%	361%
Rate per Crop Year (kg/ha)								
Glyphosate	1.00	1.10	1.20	1.26	1.32	1.40	1.49	1.58
Other Herbicides	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.41
Total Herbicides	0.47	0.48	0.50	0.53	0.57	0.62	0.67	0.72

	2011 Baseline	2013	2015	2017	2019	2021	2023	2025
kg Active Ingredient								
Glyphosate	679,509	920,187	1,180,775	1,790,978	2,464,482	3,169,271	3,832,765	4,552,624
Other Herbicides	4,094,772	4,215,519	4,211,641	4,067,660	3,875,237	3,716,276	3,521,707	3,328,597
Total Herbicides	4,774,281	5,135,706	5,392,416	5,858,638	6,339,719	6,885,547	7,354,472	7,881,221
Scenario 3: Targeted Adoption								
Percent Hectares Treated								
Glyphosate	27%	29.5%	32%	36.8%	41.6%	46%	50%	54%
Other Herbicides	375%	367.4%	360%	354%	348%	342.7%	338.1%	333%
Total Herbicides	402%	397%	392%	391%	390%	389%	388%	387%
Rate per Crop Year (kg/ha)								
Glyphosate	1.00	1.10	1.20	1.26	1.32	1.37	1.42	1.46
Other Herbicides	0.43	0.43	0.42	0.42	0.41	0.41	0.40	0.40
Total Herbicides	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55
kg Active Ingredient								
Glyphosate	679,509	875,661	1,079,565	1,345,061	1,627,340	1,911.515	2,149,112	2,397.816
Other Herbicides	4,094,772	4,255,241	4,294,305	4,306,159	4,273.497	4,247,007	4,143,682	4,040,705
Total Herbicides	4,774,281	5,130,902	5,373,870	5,651,221	5,900,837	6,158,522	6,292,794	6,438,521

D. Uncertainties in the Projections of Herbicide Use through 2025

The pace of technological change in agriculture is swift and its direction hard to predict. It is also difficult to accurately project the relative demand, supply, and market price of primary crops and production inputs. Public attitudes and policies change, as does the ability of scientists to estimate the costs, benefits, and risks associated with alternative farming systems and technology.

All these factors contribute layers of uncertainty in projecting weed management systems and herbicide use over a 15-year period in a geographic region as diverse as the 27-member states of the EU.

While the actual hectares planted to the three major crops analyzed herein is sure to differ somewhat from the projections for 2012-2025, these differences are not likely to substantially alter this study's findings. The one exception would be a major shift away from, or toward more maize production, the crop that clearly dominates the results of this study in terms of changes in herbicide use.

The EU is composed of countries that have adopted herbicide-intensive weed management systems (e.g., the U.K., Netherlands), and other countries that use herbicides more sparingly (e.g., Romania, Spain). Approval of RR crops in countries that are already heavily dependent on herbicides will trigger shifts among the products applied, but less overall increase in total herbicide use. The projections in scenarios 2 and 3 assume that farmers in countries now spraying relatively less herbicide will become incrementally more herbicide intensive, but not nearly to the level of U.K. or Dutch farmers. This assumption could prove wrong if, for example, growth in the demand for non-GE animal feed in Western Europe is met by an expansion of non-GE crop production in Eastern Europe.

This analysis assumes that RR crop technology is the only GE, herbicide-tolerant technology approved for use between now and 2025. If RR technology is approved, it is possible that other herbicide-tolerant crops will also gain regulatory approvals. More than one GE-HT option will likely drive down the premium charged for HT seeds and associated herbicides, in turn increasing overall demand. Additional HT crop options will alter the mix of herbicides sprayed, but will likely still increase overall herbicide use as measured in kg applied, with one caveat. If the biotechnology-seed industry focuses on developing HT crops engineered to withstand applications of low-dose herbicides, the overall volume of herbicide active ingredient applied could fall as a result. While the volume of herbicides applied might decline, the intensity, cost, and environmental consequences of herbicide use may actually rise as a result of the use of more biologically active and persistent herbicides.

How the EU and its member states implement the relatively new "Sustainable Use of Pesticides Directive" (EU Parliament 2009) could impact the adoption of RR crops and might shift demand toward lower-dose herbicides. Other pesticide regulatory policy changes could also have an impact on projections of "Other Herbicide" use over the 2012-2025 period, since some older, relatively high-rate herbicides may be found to pose unacceptable human health or environmental risks.

While several older, higher-rate herbicides face slipping efficacy because of the spread of resistant weeds, key low-dose families of chemistry, such as the sulfonylureas, also are plagued by dozens of resistant weeds (ISHRW 2012). Sorting out the impacts of resistance on herbicide selection is complex and dynamic, and will be driven by the degree to which farmers in the EU are able to diversify weed management tactics including crop rotation, tillage and cultivation, the planting of cover crops, and applications of herbicide. Equally important, farmers must spread out herbicide-resistance selection pressure on weed populations by not relying too heavily on any one herbicide, or herbicide family of chemistry. In short, the key to sustainable weed management is use of "many little hammers" (Liebman & Gallandt 1996).

While there are now fewer glyphosate resistant weeds in the EU than the U.S., there are several weed species in the EU that are either resistant to glyphosate, or partially tolerant of it. If RR crops are widely planted in the EU, they could spread rapidly. The faster resistant weeds spread, the steeper the upward trajectory in per hectare herbicide use. Accordingly, whether and to what extent EU authorities, the seed industry, and farmers adopt effective weed resistance-management practices will be of great consequence. Scenario 3 was designed to project the maximum increase in glyphosate use consistent with a solid commitment to resistance management.

Significant uncertainty arises from the relative lack of understanding of the long-term environmental and human health impacts of heavy reliance on RR technology. While several studies have been conducted or sponsored by industry on the toxicological properties of glyphosate and other herbicides, there has been very few high quality, long-term studies on the human health impacts of GE foods, and virtually none on the capacity of novel proteins in GE food to trigger epigenetic changes during human fetal development.

The vast majority of the GE maize and soya grown around the world are fed to animals or put through an industrial process that breaks down all or most of the transgenic proteins that are present in the raw agricultural commodity. As more GE crops are marketed that are consumed directly by people in relatively unprocessed forms, exposure to transgenic proteins will surely increase and their health consequences will likely be explored using state-of-the-art, long-term testing methods.

If and as evidence emerges that enhances or erodes confidence in the safety of GE crop technology, HT crop adoption patterns are likely to shift.

IV. Resistant Weeds – The Achilles Heel of Herbicide-Tolerant Crop Technology?

The first Monsanto petitions for approval of glyphosate-tolerant, RR soybeans and cotton were submitted to U.S. regulatory agencies in the first half of the 1990s. During this period, Monsanto scientists wrote or co-authored several papers that asserted that the evolution of weeds resistant to glyphosate was unlikely (Padgette et al. 1995; Bradshaw et al. 1997). They cited as evidence in support of this claim the near-absence of glyphosate-resistant weeds, despite millions of hectares treated with glyphosate worldwide since the mid-1970s. Technical arguments grounded in glyphosate's complex, and then only partially understood mode of action, were also advanced.

Respected weed scientists disagreed and spoke up publicly e.g., Van-Gessel (1996). Dr. Ian Heap, long-time manager of the international database on herbicide-resistant weeds (ISHRW 2012), warned in a 1997 conference presentation that resistance was highly likely in the absence of disciplined resistance-management plans (Heap 1999). He argued that herbicide-tolerant technology would impose more severe selection pressure on weed populations because of the inherent and distinguishing attribute of HT crops – the ability to spray a broad-spectrum herbicide several times after a crop has emerged, controlling weeds competing with the crop but leaving the crop unharmed.

Heap went on to argue that glyphosate would need to be used in conjunction with multiple resistance-management practices, including non-chemical weed control methods (Heap 1999). A 1996 report by the U.S.-based Consumers Union made the same case (Benbrook et al. 1996). It stated that HT crops are "custom-made" for accelerating resistance.

A. A Short History of Glyphosate Resistance in the United States

Glyphosate was approved for use in 1974 and was applied as a burn-down herbicide prior to planting, and after harvest to clean up late-germinating weeds. It was also used extensively in non-crop areas like along roads, railroad and power line rights of ways, and in lumberyards and a variety of industrial settings. A significant share of applications throughout the 1980s and early 1990s were in conjunction with no-till planting systems, and it was popular among farmers raising fruits and nuts, who sprayed it between the rows in vineyards, groves, and orchards (see NASS fruit crop pesticide use surveys covering 1991 through 2011).

In 1996, rigid ryegrass (*Lolium rigidum*) became the first glyphosate-resistant weed documented on the International Survey of Herbicide-Resistant Weeds (ISHRW) website (ISHRW 2012). Dr. Steve Powles documented this population of glyphosate-resistant rigid ryegrass in Australia in an area following a wheat (*Triticum aestivum*)-fallow-sorghum (*Sorghum bicolor*) rotation. A second population was found in 1997 in a New South Wales apple (*Malus domestica*) orchard (ISHRW 2012).

The criteria used by the ISHRW in judging whether a given population of weeds is resistant to an herbicide are strict. Each of the below criteria must be met --

1. Fulfillment of the Weed Science Society of America (WSSA) definition of resistance and the survey's definition of an herbicide-resistant weed.
2. Data confirmation using acceptable scientific protocols.
3. The resistance must be heritable.
4. Demonstration of practical field impact.
5. Identification as a problem weed to species level, and not the result of deliberate/artificial selection.

ISHRW Definition of Herbicide Resistance

"The evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal rate in an agricultural situation" (ISHRW 2012).

Individuals reporting newly resistant weeds are required to compile and submit substantial laboratory data on the population in order to prove that resistance has indeed evolved. These hurdles are one factor explaining why the ISHRW under-reports the actual extent of the problem.

Glyphosate-tolerant maize, soya and cotton were approved for use in the U.S. in time for commercial sales in 1996. Adoption rates rose rapidly in soybeans and cotton, reaching 44% and 26% respectively in just the third year on the market (1998) (Fernandez-Cornejo & McBride 2002). Farmers raising maize were slower to adopt the technology. It took ten years for RR maize to gain 25% market share, although adoption has rapidly increased since and will soon exceed 90% (NASS Acreage Reports, multiple years). The RR market share in both soya and cotton has exceeded 90% since 2007.

According to the ISHRW, horseweed (*Conyza canadensis*), also known as marestail, was the first weed species to develop resistance to glyphosate in the U.S. because of selection pressure associated with RR technology (ISHRW 2012). The resistant population was found in 2000 in Delaware in several hundred sites, with a total infestation reported as between 10,000 and 100,000 acres. Dr. Mark Van-Gessel provided the data to the ISHRW. He and colleagues carried out extensive tests exploring the degree and mechanism of resistance (Zelaya et al. 2004). Two more resistant populations were found in other states in 2001, and another five in both 2002 and 2003. Today, 23 states have documented populations of glyphosate-resistant horseweed (ISHRW 2012).

The number of glyphosate-resistant weeds rose from two to five in 2004, the year that the ISHRW confirmed that three new weeds had became glyphosate resistant in the U.S. – common ragweed (*Ambrosia artemisifolia*), giant ragweed (*Ambrosia trifida*), and Italian ryegrass (*Lolium multiflorum*). A no-till soya field in Missouri was the source of the first documented case of common ragweed (Hartzler 2004). RR soya had been planted continuously since 1996, in some years in a double-crop rotation with wheat.

The year 2005 was the glyphosate-resistant weed tipping point in the U.S. Ten new state-weed combinations were confirmed that year by the ISHRW. Most ominously, glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and common waterhemp (*Amaranthus tuberalatus syn. rudis*) were confirmed – two of the most prolific, aggressive, common, and costly weeds spread widely across America's major farming regions.

In the first nine years of RR crop use in the U.S., glyphosate resistant weeds were documented in 17 new state-weed combinations. In the next seven years, 2005-2011, another 71 state-weed combinations were confirmed by ISHRW. Four weeds are now present in 12 or more states, as shown in Table 4.1.

Today, the ISHRW website lists 23 glyphosate-resistant (GR) weed species in the U.S. and a total of 88 newly confirmed, state-resistant weed combinations, of which 81% has emerged in the last seven years.

Each state-glyphosate resistant weed case listed by the ISHRW includes an estimate of the number of sites with the resistant weeds and a minimum and maximum estimate of the acres infested. The ISHRW alerts users of their data, however, that the estimates of acres/hectares infested are uncertain and likely low, because of difficulty in actually determining how widespread a presumptively resistant weed has become. In addition, the data on area infested are not kept up-to-date. For example, the ISHRW lists only 40.5 ha of glyphosate-resistant waterhemp in Illinois on one site reported to the ISHRW in 2006. A Southern Illinois University weed scientist estimates that 2.0 to 2.4 million hectares are now infested just in Illinois (Lawton 2012).

Notwithstanding these shortcomings, Table 4.2 reports ISHRW data for glyphosate-resistant weeds in the U.S. and shows that by 2011, over 4.45 million hectares were infested. The estimates of area infested are mid-range values between the reported minimum and maximum area infested, and significantly underestimate the actual impacted area (Ian Heap email to C. Benbrook 8/2/2012).

Table 4.1 Number of States with Newly Reported, Documented Cases of Glyphosate Resistant Weeds, 1996-2011

Weed Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Total 1996-2011**
Palmer Amaranth *(Amaranthus palmeri)*										2	2	1	4	1	2	2	**14**
Common Waterhemp *(Amaranthus tuberalatus)*										1	2	1		2	3	3	**12**
Common Ragweed *(Ambrosia artemisifolia)*									2		1	4	1				**8**
Giant Ragweed *(Ambrosia trifida)*									1	2	3	1	1	2	3		**13**
Hairy Fleabane *(Conyza bonariensis)*												1		1			**2**
Horseweed *(Conyza canadensis)*					1	2	5	5		4	1	2		1	1	1	**23**
Junglerice *(Echinochloa colona)*													1				**1**
Goosegrass *(Eleusine indica)*															1	1	**2**
Kochia *(Kochia scoparia)*												1		1		1	**3**
Italian Ryegrass *(Lolium multiflorum)*									1	1			1		1		4
Rigid Ryegrass *(Lolium rigidum)*			1														1
Annual Bluegrass *(Poa annua)*															1	1	2
Johnsongrass *(Sorghum halepense)*												1	1		1		3
Total:	0	**0**	1	0	1	2	5	5	4	10	9	12	9	8	13	9	88

Source: Weed Science Society of America's list of "Glycine Resistant Weeds" accessed 7/15/2012 via www.weedscience.org
* Newly documented cases from reports posted through July, 14 2012.

What Is Driving the Resistant Weed Problem?

Why have glyphosate-resistant (GR) weeds become such a serious problem? Heavy reliance on a single herbicide has placed weed populations under intense, selection pressure (Mortensen et al. 2012) -

- RR crops make it possible to extend the glyphosate application window to most of the growing season, instead of just the pre-plant and post-harvest periods,
- RR technology allows multiple applications of glyphosate in the same crop year, and
- The rotation of RR corn-RR soybeans, or any two RR crops, exposes weed populations to annual and repetitive glyphosate-selection pressure.

These factors constitute a sort of "perfect storm" for the emergence of glyphosate-resistant weeds. In Palmer amaranth (*Amaranthus palmeri*), resistance to glyphosate has been traced to amplification in the expression of the key EPSPS gene (5-enolpyruvylshikimate-3-phosphate synthase) (Gaines et al. 2010). Resistant weed populations from Georgia contained 5-fold to 160-fold more copies of the EPSPS gene, compared to susceptible plants (Gaines et al. 2010). Moreover, the scientists note that EPSPS gene amplification is heritable, leading the team to warn that the emergence of glyphosate-resistant weeds "endangers the continued success of transgenic glyphosate-resistant crops and the sustainability of glyphosate as the world's most important herbicide."

Other factors trigger their spread. Storm events, floods, animals, machinery, and other factors can disperse resistant-weed seeds far and wide across landscapes. If weed seeds with an herbicide-tolerant gene land in fields also planted to RR varieties, glyphosate-selection pressure will persist; there will be more resistant weeds, some of which will go to seed, expanding the population of GR weeds.

Table 4.2 Spread of Glyphosate-Resistant Weeds in the United States: 2000-2011

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Glyphosate Resistant Weeds												
Number of Sites (Mean)	301	754	621	319	9	61,562	11,864	1,398	428	100,083	431	424
Cumulative total	301	1,055	1,675	1,994	2,003	63,565	75,429	76,827	77,255	177,338	177,769	178,192
Acres Infested (mid-point of estimated range)												
First Report	55,001	3,500,076	61,853	11,610	410	4,655,833	1,167,880	67,295	22,904	1,511,377	18,029	61,782
Cumulative Total	55,001	3,555,076	3,616,929	3,628,539	3,628,948	8,284,781	9,452,661	9,519,956	9,542,859	11,054,236	11,072,265	11,134,047
Acres Planted to Herbicide-Resistant Crops												
Total	55,188,354	67,928,199	74,176,514	81,086,438	90,380,071	95,334,698	108,216,757	116,256,822	132,440,101	137,710,744	143,876,230	149,983,376

Source: International Survey of Herbicide Resistant Weeds (ISHRW), 2012

A team of scientists spent over four years mapping, measuring and modeling the spread of glyphosate-resistant horseweed (*Conyza canadensis*) in the Northeast, mid-Atlantic and Midwestern states (Dauer et al. 2009b). They focused on the movement of weed seeds up into the atmosphere's surface boundary layer (SL) to heights in the range of 68-120 m above ground. Weed seeds reaching this altitude tend to stay in airborne for several hours and with a modest wind (17.5 km/hour) travel an estimated 87 km to 122 km (Dauer et al. 2009b).

A typical horseweed plant produces 130,000 seeds over a six-week period. Waterhemp (*Amaranthus tuberalatus syn. rudis*) plants produce about 400,000 seeds. If just one resistant waterhemp plant goes to seed in a crop field, it could lead to 6.25 million resistant waterhemp plants two seasons later (PFS Scoop 2011). When even a few resistant weed seeds reach the upper atmosphere at the time of an extreme weather event, resistant seeds can disperse over several hundred kilometers (Dauer et al. 2009b). Other research has shown that resistant-weed seeds tend to rapidly fill in spaces where resistant seeds have not previously fallen, especially in relatively homogenous landscapes (Dauer et al. 2009a).

B. Current and Projected Spread of Glyphosate-Resistant Weeds

Glyphosate-resistant weeds have spread so rapidly in the U.S. that weed scientists have not been able to keep the ISHRW up-to-date by collecting the data needed to confirm newly resistant populations. Academic weed scientists, commodity organizations, and the agrochemical industry have compiled more complete inventories of resistant weeds, and also have projected trends likely to unfold over the next decade.

In 2011, a Syngenta weed scientist, Charles Foresman projected that glyphosate-resistant weeds would infest 15.4 million ha in in the U.S. in 2013 (Foresman 2012). This Syngenta forecast was widely regarded as shocking when it was issued in 2011, given that the ISHRW had documented "only" just over 4.5 million ha of glyphosate-resistant weeds in the U.S. as of 2011. But even Syngenta's estimate of 15.4 million ha infested in 2013 likely underestimates the rapid rate of spread of glyphosate-resistant weeds, as evident in data from the Red River Valley (Stachler 2012) and a comprehensive survey carried out by Dow AgroSciences (Blewett 2011), a U.S.-based company developing and selling herbicide-tolerant crop technology.

The rapid spread of resistant weeds in the Red River Valley (RRV) in North Dakota and Minnesota has been carefully documented by university weed scientists (Stachler 2012). In 2007, there was only one RRV area with known or suspected glyphosate-resistant common ragweed, giant ragweed, or waterhemp. Two years later, up to 95% of the cropland in some areas was infested, and in most of the Valley's intensively cultivated areas, 30% of the cropland was infested with one or more GR weed.

By 2011, the majority of cropland in several RRV areas was infested with at least one glyphosate-resistant weed and in one hot-spot, 5% to 30% of the cropland was infested with GR giant ragweed and waterhemp. The presence of two resistant weeds in a field usually requires farmers to apply two or three additional herbicide active ingredients, which is why herbicide use rises so sharply when multiple-resistant weeds gain a foothold in farm fields.

To provide farmers new tools to combat glyphosate-resistant weeds, all the major biotech-seed companies in the U.S., and indeed worldwide, are investing heavily in a new generation of crops engineered to resist multiple herbicides in a wide range of combinations including glyphosate, glufosinate, the synthetic auxin/phenoxy herbicides 2,4-D and dicamba, the aryloxyphenoxypropionate ("fop") grass herbicides, paraquat, and several others. About two-thirds of the petitions for deregulation of GE crops pending before the USDA address crops that are destined to become part of multiple-herbicide-tolerant cultivars (APHIS 2012).

Dow AgroSciences has developed maize varieties tolerant to the phenoxy herbicide 2,4-D, glyphosate, glufosinate, and the so-called "fop" herbicides. It has also developed soya tolerant to glyphosate, 2,4-D and dicamba. These new technologies comprise the "Enlist Weed Management System" (Dow AgroSciences 2012).

Over the last two years Dow AgroSciences has provided the USDA a substantial body of data in support of its pending petition to deregulate (approve) the company's new 2,4-D herbicide-tolerant maize. As part of its submission, Dow AgroSciences included the results of a comprehensive national survey focusing on the percentage of maize and soybean hectares infested with glyphosate-resistant weeds. The survey sought information from university-based weed scientists with knowledge of the specific resistant weeds that farmers are contending with in their state (Blewett 2011).

The results of the survey cover three to four major GR weeds and are reported as average degrees (percent) of presence for Northern and Southern states, in recognition of the major differences in the presence of various GR weed species in these two regions of the U.S.

The results are striking and confirm the dire warnings made by university weed scientists (Mortensen et al. 2012; Duke 2011; Owen 2011; Harker et al. 2012). By 2010, 26.5% of Northern soybeans were infested with GR horseweed, while 44% of Southern soybeans were infested with both GR horseweed and Palmer amaranth (Blewett 2011).

Table 4.3 Projections by Dow AgroSciences of the Spread of Glyphosate-Resistant Weeds in Corn and Soybeans in the Northern and Southern States, 2010-2020.

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**
Northern Soybeans --							
Marestail	26.5%	29.00%	31.4%	33.8%	36.3%	38.7%	50.8%
Giant Ragweed	9.5%	12.2%	14.9%	17.6%	20.3%	22.9%	36.3%
Waterhemp	18.4%	21.0%	23.7%	26.3%	28.9%	31.6%	44.8%
Three Weeds Total	54.4%	62.2%	70.0%	77.7%	85.5%	93.2%	131.9%
Best Estimate of % With One or More Weeds	40.5%	45.6%	50.7%	55.8%	60.9%	66.0%	91.4%
Southern Soybeans --							
Marestail	43.8%	48.2%	52.6%	57.0%	61.4%	65.8%	87.7%
Palmer Amaranth	44.3%	54.0%	63.6%	73.3%	83.0%	92.7%	100.0%
Two Weeds Total	88.1%	102.2%	116.2%	130.3%	144.4%	158.5%	187.7%
Best Estimate of % With One or More Weeds	66.2%	78.1%	89.9%	100%	100%	100%	100%
Northern Corn --							
Marestail	19.4%	21.7%	24.0%	26.3%	28.6%	30.9%	42.3%
Giant Ragweed	9.0%	11.3%	13.6%	15.8%	18.1%	20.4%	31.7%
Waterhemp	16.6%	19.5%	22.5%	25.4%	28.4%	31.4%	46.2%
Three Weeds Total	45.0%	52.5%	60.1%	67.5%	75.1%	82.7%	120.2%
Best Estimate of % With One or More Weeds	30.8%	36.0%	41.3%	46.5%	51.8%	57.1%	83.2%
Southern Corn --							
Marestail	34.4%	40.6%	46.9%	53.1%	59.4%	65.6%	96.9%
Palmer Amaranth	34.5%	39.3%	44.0%	48.8%	53.6%	58.3%	100.0%
Two Weeds Total	68.9%	79.9%	90.9%	101.9%	113.0%	123.9%	196.9%
Best Estimate of % With One or More Weeds	51.7%	59.6%	67.5%	75.4%	83.3%	91.1%	100.0%
Soybean National Average	**53.3%**	**61.9%**	**70.3%**	**77.9%**	**80.5%**	**83.0%**	**95.7%**
Corn National Average	**41.3%**	**47.8%**	**54.4%**	**60.9%**	**67.5%**	**74.1%**	**91.6%**
Soybean Acres Planted	77,404,000	75,208,000	76,000,000	76,000,000	76,000,000	76,000,000	76,000,000
Corn Acres Planted	88,482,000	92,282,000	95,000,000	93,000,000	93,000,000	93,000,000	93,000,000
Projected Acres Infested With One or More Glyphosate-Resistant Weed --							
Soybeans	41,275,683	46,516,148	53,428,000	59,185,000	61,142,000	63,061,000	72,713,000
Corn	36,498,825	44,110,796	51,656,250	56,637,000	62,798,250	68,889,750	85,188,000
Two Crop Total	**77,774,508**	**90,626,944**	**105,084,250**	**115,822,000**	**123,940,250**	**131,950,750**	**157,901,000**

Source: Infestation data from page 78, Tables 11 and 12 in "Supplemental Information for USDA Petition for Nonregulated Status of DAS-40278-9 Corn," Dow AgroSciences LLC, submitted by T. Craig Blewett, June 20, 2011. (Blewett 2011) "Best Estimate of % With One or More Weeds" calculated by C. Benbrook, based on assumption that one-half of the area infested by the second most common resistant weed would be present on acres not infested by the most prominent resistant weed. In the case of three resistant weeds, it is assumed that one-half of the sum of the area infested by the second and third most common resistant weed fall on acres other than those infested by the most prominent resistant weed. The area infested is truncated at 100%. Acres infested calculations by C. Benbrook.

Data reported in the Dow AgroSciences survey suggests that over 12 million hectares of cropland producing soybeans were infested with glyphosate-resistant weeds in 2010. Across the major resistant-weed species noted in Table 4.3, almost 37 million hectares were impacted – about eight-times more than the mid-range ISHRW estimate of 4.5 million hectares.

In Table 4.3, the percent of soya and maize acres infested with the listed weeds are directly from the Dow AgroSciences submission (Blewett 2011, Tables 11 and 12).

The next row adds together the percentage of cropland infested by the two or three major glyphosate-resistant weeds, but over estimates the percent of cropland infested to the degree that some acres are infested with two, and a few with three or more resistant weeds.

An estimate of the percent of soya and maize acres infested with one or more GR weeds was made by assuming that one-half of the area infested with the second most common resistant weed are not also infested with the most common resistant weed. In cases like Northern soybeans in which three resistant weeds are covered, it is assumed that one-half of the area infested with the second and third most common weeds fall on land not infested by the most prominent weed.

The row of data "Best Estimate of % With One or More Weeds" reports the outcome of this calculation, and shows that "only" 30.8% of maize in Northern States was infested with a glyphosate-resistant weed in 2010, whereas 66.2% of Southern soybeans were.

The last three rows of data show the "best estimate" of the land area of soybeans and corn infested with one or more glyphosate-resistant weeds. Infestations covering 31.5 million hectares in 2010 rise steadily to 64 million in 2020 -- 93% of the total hectares projected by USDA to be planted to these two major row crops in 2020, and nearly one-half of America's cultivated cropland base.

C. Resistant Weeds in the European Union

There are 12 cases of GR weeds in EU countries. GR Hairy fleabane (*Conyza bonoriensis*) in Spain was the first documented case in the ISHRW, and was recorded in 2004. There are now five GR weed species in Spain and two in Italy, and one in the Czech Republic, France, Greece, Poland, and Portugal (ISHRW 2012).

Clearly, the problem with resistant weeds is more serious in southern Europe. Most of the documented cases arise from repeated glyphosate use in vineyards, orchards, and olive groves, rather than in annually cultivated crops.

It is difficult to predict whether already resistant, or near-resistant weed species in Europe might spread across landscapes, moving from one crop to another. The highest risk scenario would arise in parts of Spain, if and where RR maize or soya is planted in the vicinity of orchards or groves where GR weeds are established. Horseweed is one of the already-resistant weeds in Spain and its ability to thrive in maize and soya fields has been amply demonstrated in the U.S.

For this reason, if RR crops are approved for planting in the EU, special diligence needs to be exercised in Spain and other countries in southern Europe were GR weeds are already established in areas where RR crops will be sown.

But even in the absence of any GR weeds, European farmers adopting and relying on RR varieties to the same degree that U.S. farmers did from 1996 through 2011 will have to deal with resistant weeds within a few years of commercial adoption. The problem will grow more serious and spread for about a decade, but then will likely expand rapidly.

Presumably, EU farmers, weed scientists, and government officials will not repeat the mistakes made in the U.S. and will develop and implement strong resistance management programs. If they do not, the outcome is predictable, the only uncertainties are how fast resistant-weed populations will emerge and spread, and what EU farmers will do in response to their presence.

V. Ecological, Public Health, and Economic Impacts of Widespread Adoption of Herbicide-Tolerant Crops

The approval and widespread planting of Roundup Ready (RR) maize, soya, and sugar beets in the EU would dramatically increase reliance on glyphosate, reduce the frequency of use and/or the application rates of some other herbicides, and increase overall herbicide use. The percentage changes brought about in Scenario 2 in total herbicide use are comparable in maize and soya. The increase in reliance on glyphosate is greater in soya than maize. In 2025 in Scenario 2 (Unlimited Adoption), glyphosate accounts for 83% of soya herbicide use, and 68% in the case of maize.

The public health and environmental implications of these changes in herbicide use are complicated to project for a host of reasons. The impacts of herbicides on non-target organisms depend on dose levels and concentrations, the timing of exposures, the persistence of exposures, and what other chemicals, or sources of stress, the organisms might be exposed to in the same time period. There are also many things a farmer can do in the course of managing pest management systems to alter the quantity of pesticide that must be applied, and to lower non-target organism exposure levels stemming from applications.

A. Presence in the Environment

If, and as, glyphosate use increases in the EU, new exposure pathways, coupled with higher concentrations, will lead to higher exposure levels for non-target organisms ranging from birds and bees, to frogs, fish, earthworms, plants, and people.

Glyphosate is now present in the soil, air, rainfall, some foodstuffs, and drinking water in many regions around the world. In recent U.S. Geological Survey testing in farming regions dominated by RR crops in the U.S., glyphosate was found in 60% to 100% of rain and air samples (Chang et al. 2011).

Chang and colleagues (2011) report that some 97% of the glyphosate in air is removed by a rainfall event lasting at least 30 minutes. Nearly every stream, river, and reservoir in heavily farmers regions contains runoff of glyphosate and its degradation products (most notably aminomethylphosphonic acid [AMPA]). The frequency of detections in groundwater is rising, especially wherever glyphosate-based herbicide-resistant technology now dominates weed-management systems (Borggaard & Gimsing 2008; Coupe et al. 2011).

Heavy reliance on glyphosate-based weed-management systems in North America has altered landscapes and plant biodiversity. For example, it has reduced milkweed (major food source for Monarch butterflies (*Danaus plexippus*)) populations in the Midwest by 58%, coinciding with an 81% decline in Monarch populations in the Midwest (Pleasants & Oberhauser 2012).

An extensive U.K. study analyzed the impact of RR technology on infield and field-edge biodiversity in sugar beet fields. The "Field Scale Evaluations" (FSE) study encompassed 68 maize sites, 66 sugar beet, and 67 oilseed rape (*Brassica napus var. napus annual*) fields (Firbank et al. 2003). The maize was engineered to tolerate glufosinate ammonium, an active ingredient that has an impact on weed populations similar to glyphosate.

The scale of this study was, and remains unprecedented. The team carrying out the FSE counted 700,000 plants, 17,000 bees, 13,000 butterflies during the course of over 4,000 field visits (Dewar 2003). The study reported no significant differences in the impacts of conventional and herbicide-tolerant production systems on invertebrates, pests, or natural enemies. There was a statistically significant reduction in bees in GE sugar beet fields, and a decline in butterflies in sugar beets and oilseed rape. Not surprisingly, there were also declines in weed seedbanks, undermining a part of the food chain supporting upland bird populations.

While RR maize was not included in the FSE, when applications of glufosinate ammonium on HT maize were compared with the use of the herbicide atrazine in conventional (non HT) maize, there was a beneficial impact on weed biomass and seedbanks, although the impacts were greatly reduced when atrazine was factored out of the spray program (Perry et al. 2004). Use of atrazine has been banned in the EU since the FSE was carried out.

The herbicide use regimes in the FSE reflected applications of glyphosate required prior to the emergence of resistant weeds, and before farmers are forced to deploy additional herbicides. For this reason, the absence of negative impacts on biodiversity in the HT maize is not likely to apply to herbicide-tolerant cropping systems that have been in place long enough for resistance to trigger increases in herbicide use.

B. Relative Ecotoxicity

Complex challenges arise in the course of assessing the relative ecological impacts of different weed management systems. In general, chemical herbicides reduce the need for, and reliance on tillage, crop rotations, and cover crops in managing weeds. They are compatible with reduced tillage systems that lessen the risk of soil erosion, and are necessary in making most no-till systems viable. However, these systems undermine biodiversity, often lead to herbicide-contaminated drinking water, and can place aquatic ecosystems at risk. Occupational or application-related exposures to mixer-loaders, farmers, and rural neighbors can increase the risk of a variety of health problems including cancer, birth defects, and immune system impairment.

Organic systems completely eliminate the ecological impacts of herbicides, since there are no organically approved herbicides suitable for field-scale applications. Organic row crop and small grain systems rely on pre-plant tillage, coupled with cultivation during the early stages of the growing season, to keep weed pressure to a minimum. Because the efficacy of tillage in weed management is highly dependent on the timing of field operations and the skill of operators, weed control is more variable in organic systems, and in some years, competition from weeds reduces yields. Over time, weed seedbanks usually decline on well-run organic farms, and weed pressure declines proportionally. Still, achieving consistent weed control without chemicals is typically the most difficult management challenge on organic maize, soya, and sugar beet farms.

It is widely accepted that organic farmers must rely more on tillage, and as a result, the risk of soil erosion is increased in organic systems. It is less well known that changes in soil quality on organic farms, coupled with gradual reductions in weed seedbanks, lowers the risk of erosion. By building soil organic matter, organic farming systems reduce the risk of erosion in three ways –

- Increasing organic matter tends to reduce bulk density and minimize compaction, and this increases the rate at which rainfall enters the soil. Faster infiltration leaves less water on the surface, available to flow off the land, carrying soil with it.
- Soils higher in organic matter hold more water, hence reducing the volume of water either running off the land, or moving down into groundwater or till drainage systems.
- Soil aggregates on organic farms are more tightly bound together as a result of higher levels of soil microbial activity, which deposits sticky substances in the soil that lower the risk of erosion.

Many factors impact the efficacy and ecological impacts of conventional, herbicide-based weed management systems in contrast to organic systems dependent on cultural practices and tillage. No system is dominant across all conditions, and all systems are vulnerable under certain combinations of conditions. Level of management, timing, and operator skill are more important to success in organic systems, compared to herbicide-tolerant systems. Indeed, one of the factors driving rapid adoption of the RR system in the U.S. was its simplicity and forgiving nature. In the RR system, especially before the emergence of GR weeds, glyphosate can be re-applied if a previous application washes off or does not work well enough. Applications at one-half, or twice, the typical rate cause no major problems, and if the weather or a machinery breakdown causes a delay in an application, a slightly higher rate a few days later will usually work just as well.

Quantifying the Ecological Impacts of Weed Management Systems

Most approaches for the comparative assessment of pesticides are hazard-based. They typically score the impacts of one herbicide in contrast to others relative to a series of toxicity endpoints from standard laboratory tests. Application rates may or may not factor in such comparisons. The more sophisticated relative-risk systems derive non-target, species-specific exposure estimates through models driven off field-level parameters, much as regulatory authorities typically do. However, even those approaches that attempt to combine toxicity and exposure into an actual measure of risk typically have shortcomings in a number of key areas:

1. Most do not address inter-species differences in toxicological susceptibility, a key source of uncertainty.
2. Local conditions are not taken into account including factors such as rainfall, proximity to water bodies, and soil type in producing context-specific risk scores.
3. Risk scores are not adjusted for formulation, application methods, or timing, key factors that can alter exposure levels.
4. Estimated risk scores are not calibrated, nor validated against documented field impacts.

Systems designed to take some or all of the above factors are being developed in both Europe and the U.S., but none are now complete. In the U.S., the Pesticide Risk Mitigation Engine (PRiME) was developed with the support of a Conservation Innovation Grant administered by the U.S. Department of Agriculture's National Resource Conservation Service. Since 2009, numerous partners in the agricultural and food industry sectors, and government agencies have supported the ongoing development, calibration, and field-testing of PRiME.

It is not currently possible to carry out a comprehensive assessment of the relative risks of different weed management systems and technology that takes into account the full array of possible impacts. Preliminary studies in the literature on the ecological impacts of herbicide-tolerant cropping systems have documented a number of novel, adverse impacts on soil microbial communities, soil nutrient levels and bioavailability, levels of soil-borne pathogens, water use efficiency, nitrogen fixation, and above-ground biodiversity (Bennett et al. 2004; Devos et al. 2008; Dewar 2003; Firbank et al. 2003; Manny et al. 2010; Marlander et al. 2003; Peterson & Hulting 2004). Most studies of herbicide-based systems have documented tradeoffs across systems, whereby some risk endpoints rise, others fall, and many are left largely unchanged.

C. Impacts on Farmer Choice, Farming Systems and Economic Performance

In addition to a host of impacts on weed management systems, herbicide use, and the environment, adoption of GE herbicide-tolerant (HT) technology in the EU will likely lead to changes in farmer costs-of-production and net income. Many factors will determine the degree of economic impacts including –

- Whether one or multiple sources of GE-HT seeds become available at the same time,
- The emphasis the seed industry places on increasing the share of seed bred and sold for a crop that are GE-HT cultivars, in contrast to the supply, diversity, and quality of non-GE seeds,

- The price of GE-HT seeds, and associated herbicides (especially glyphosate), relative to the price of non-GE seeds and the herbicides typically used in conjunction with them, and
- Trends in agricultural commodity, fertilizer, machinery, chemical, land and labor costs.

One way to gauge the possible magnitude of the economic impacts of HT weed management systems is to assess the U.S. experience since adoption of RR technology in 1996. Such impacts in the U.S. are likely to be high-end estimates of possible impacts in the EU, since it is unlikely that HT seed adoption in the EU would progress as fast or as far as in the U.S. For this to happen, member states would have to largely ignore, in the area of weed management, the EU "Sustainable Use of Pesticides" directive (2009/128/EC) (see Chapter II for an explanation of the reasons why).

Pricing HT Seed

The first factor listed above – whether there is competition across biotechnology-seed companies selling GE-HT maize, soya, and sugar beet seeds to EU farmers – will likely play only a marginal role in modulating seed prices, because of the way biotechnology-seed companies typically set the price for GE-HT seeds. For each unique biotechnology trait (e.g., the RR trait in a soya cultivar), the industry calculates the expected difference in total weed-management costs between a soya field planted to the GE-HT seed, versus fields planted to non-GE seed. The HT-seed price premium is set roughly equal to, or a bit below, the expected difference in total weed management costs per hectare.

It is important to note that in all three major HT crops in the U.S., the efficacy of control was greatest in the first few years of adoption. Accordingly, when the biotechnology-seed companies first calculated the difference in weed management costs between a field planted to HT seed, vs. non-HT seed, the volume of herbicides applied on HT fields was at its low point. This tended to support relatively larger HT seed price premiums.

Over time in the U.S., however, weed shifts and GR weeds incrementally undermined efficacy, forcing farmers to spay more often, at higher rates, and include additional herbicides in their management programs. These responses to changing weed pressure have driven upward the total cost of HT-seed based systems, and, other things being equal, reduced their competitiveness compared to non-HT systems. But in response, the biotech-seed companies typically have not proportionally reduced the HT seed price premium, nor the licensing fees associated with access to their proprietary traits. As a result, the net economic return to farmers who plant HT seeds has been driven downward relative to farmers planting non-HT seed.

Farmer Choice

The degree of choice farmers can exercise in seed selection is another key factor that will determine the economic impacts of HT crops in the EU. If HT seeds in the EU were to gain 20% to 30% market share for a given crop, farmers would likely retain access to, and freedom to choose non-HT crop genetics that are well suited to a given farm's soils and climates. But when HT seeds account for about two-thirds or more of market share, the selection of non-GE seeds shrinks to a point where shortages will periodically occur in the supply of non-GE seed suitable for particular combinations of soils and climate.

In the U.S., GE soya and cottonseed accounts for well over 90% of sales, and GE maize is approaching 90% (NASS acreage reports, multiple years). At these levels, farmers have limited opportunities to buy high-quality, non-GE seed, and in any given year, only up to about 10% will be able to do so. Accordingly, seed market competition will be, for the most part, across HT-seed-herbicide "technology packages." The price premium associated with any given trait will be set by market conditions, and will likely differ little if multiple companies offer comparable seed with the same GE trait.

Lack of choice has implications, as well, in the ability of farmers to prevent the emergence or slow the spread of GR weeds. Suppose American farmers collectively decide that strong measures must be taken to lessen reliance on glyphosate, in order to deal with the already-severe threat posed by GR weeds. Will they be able to act?

For maize, soya, and cotton farmers in the U.S., their choice of seed dictates their reliance on certain herbicides. To the extent the available supply of seed forces most farmers to plant the vast majority of their cropland to RR varieties, farmers are not likely to lessen reliance on glyphosate.

The seed industry decides a year in advance what seed to produce and sell in the upcoming cropping season. Their collective decisions determine the degree of farmer choice. There is no magic wand that farmers can use to extract the RR gene from a bag of maize or soya seed, and once farmers in the U.S. or EU pay the premium for RR seed, they are almost certainly going to spray glyphosate.
For this reason, the biotechnology-seed industry bears significant responsibility in combating the spread of GR weeds. Thus far in the U.S., they have pursued a "more is better" strategy, through development of new, stacked GE-HT cultivars resistant to multiple herbicides.

Tracking Changes in Seed Prices

Since 2001, the USDA has collected data on the average price of "all seeds," conventional (not-GE) seed, and GE seeds. From 1975 through 2000, seed price data from USDA is reported only for "all seeds." Corn seed price data are based on a "unit" containing about 80,000 seeds. Soybean seed is sold by the 60-pound bushel, containing approximately 150,000 seeds. Cottonseed is sold by hundred-weight (CWT), with each CWT containing about 425,000 seeds.

A "Seed Price Premium-Farm Income Database" compiled by BCS was used as the source of the information on seed prices and price trends discussed in this section. The database encompasses USDA-gathered statistics on the price of seed from 1975 through 2010, as well as average seeding rates and the average cost of seed per acre.

The database includes USDA data on average crop yields, market prices for crops, variable and total production costs, and gross and net income per acre. The price of seed per acre is contrasted to gross and net income per acre, and other production costs. Changes in these variables are tracked over time. More information on the parameters in the "Seed Price Premium-Farm Income Database" is presented in Appendix A.

Soybeans Traditionally, farmers have saved soybeans from one year's harvest for cleaning and planting the next year, a practice often referred to as "brown bagging" seed. This is why for many years the price of soybean seed has not risen appreciably above the price of a bushel of soybeans, plus seed cleaning costs.

Every third or fourth year, farmers would purchase new soybean seed, particularly if a promising new variety had been recently released. If the variety performed well, the farmer would save some or all of the harvest for seed the next year, or purchase additional seed to plant the new variety on all fields. Each acre devoted to soybean seed production will plant about 30 acres the next year (Pollack 2009).

In the 1980s, U.S. soybean prices averaged about $6.00 per bushel, and soybean seed cost about $12 per bushel, so there was a two-fold premium paid for soybean seed relative to the cash price of soybeans.

In 1995, the year before the first GE varieties were marketed, soybean seed cost $13.60 per bushel, and soybeans sold for $6.72 per bushel, for a seed-to-soybean premium of 2.02, consistent with the historic norm.

Dramatic inflation in the GE-HT seed-to-soybean premium occurred in step with the adoption of RR soybeans in 1996. By 2005, the seed industry had introduced the RR trait into nearly all soybean varieties and 87% of national soybean acres were planted to RR seeds. The industry took advantage of the lack of alternatives and the popularity of the RR weed management system by escalating the pace of increases in GE soybean seed prices. The 2005 GE seed-to-soybean price ratio was 6.1, while the conventional seed-to-soybean price ratio was 3.4.

RR soybean seed prices rose dramatically in 2010 to around $53.50 per bushel, 34% above the price for RR seeds in 2008. The soybean market price paid to farmers average $11.30 in 2010, resulting in a GE-HT seed to soybean ratio around 4.7, over twice the historic norm. In the 25 years from 1975 to 2000, the "all soybean" seed price rose about 63%. In the next 12 years, the price rose another 211% (from $17.10 to $53.20).

<u>Corn</u> Farmers purchase new hybrid corn seed every year. They do so because hybrid corn yields typically exceed yields in fields planted to what is called "open-pollinated" corn. It is worth noting that some open-pollinated corn varieties still perform nearly as well as the top-yielding GE hybrids in some trials, although they tend to not do as well across a wide range of field conditions.

For the most part, corn yields have risen in step with increases in the number of seeds planted per acre. The "Seed Price Premium-Farm Income Database" includes a line reporting the average pounds of corn harvested per seed planted from 1975 through 2012. Each corn seed produced between 0.22 to 0.32 pound of corn from 1975 through 2010. The highest production per seed (0.32) occurred in 2004, a year with record-high corn yields. The major drought in 2012 in the U.S. will drive this indicator of productivity to an historic low.

Over the past 35 years, the average pounds of corn harvested per seed are essentially unchanged, despite fluctuation from year to year as a result of weather-driven yield changes. There is little evidence that GE seeds have shifted this trend line one way or the other.

Over the last 35 years, the average "all corn" price of seed has risen 4.9-fold, from $36.50 per unit (80,000 seeds) in 1975 to $217.00 per unit in 2009. In 2001, the average price of GE seed was $110.00, compared to $85.30 for conventional seed. By 2012, the GE corn seed price averaged $263.00 per unit, while conventional seed sold for an average of $167.00.

Corn growers planting the eight-trait "SmartStax" corn hybrids introduced in 2010 paid even more – as much as $320.00 per unit. SmartStax corn has cost about twice as much as conventional seeds, and nearly four-times more than conventional corn seed just 10 years earlier.

The biotechnology-seed companies have not announced the basis for establishing the premiums that will be charged for GE-RR seed in the EU. Most GE traits in the U.S. have been priced relative to the expected average change in pest management costs. The highest premiums are associated with crops with high weed management costs. For example, Monsanto had floated a price of around $100 per acre as the premium for RR strawberries, when the company was exploring whether to develop a RR version of that high-value crop. This very high premium was based on eliminating the need for costly hand weeding in strawberry fields.

In the EU, the RR crop seed premium will almost certainly be highest in sugar beets, a crop in which per ha weed management costs are markedly higher than in the case of maize and soya. In all crops, the availability of non-GE seed alternatives, and the effectiveness of non-GE weed management systems, will directly influence the size of the RR seed premium. If GE RR seeds come to dominate the seed supply, as they now do in the U.S., seed companies will have greater ability to control relative supply and demand, as well as seed price levels and premiums.

Impacts of Rising Seed Costs on Farm Income

Market prices for corn and soybeans have approached or exceeded historic highs in recent years and have been more than double the recent 10-year average. Rising volatility in crop and input prices has produced wide swings in net farm income. The consequences of the elevated cost of GE seeds for American farmers can only be understood in the context of this heightened economic variability, and vulnerability.

The cost of an input like seed relative to crop income and expenses can be analyzed in several ways, e.g.:

1. Cost expressed as a percent of gross income.
2. Cost as a percent of total operating costs.
3. Cost relative to net returns from crop production (gross crop income minus operating costs).

Clearly, farmers who must buy seed are better off when all three measures are headed downward. When seed costs rise relative to gross and net income, farm level profit margins fall, unless improved seed traits enhance performance sufficient to offset the increase in seed prices.

<u>Soybeans</u> Farmers spent about $8.32 per acre in 1975 when they purchased soybean seed. That year, gross soybean crop income averaged $141.70 per acre. Accordingly, soybean seed expenditures accounted for 5.9% of gross income per acre. From 1975 through 1997, the cost of soybean seed accounted for 4% to 8% of gross soybean crop income per acre.

In 1998 GE soybeans were planted on 44% of national soybean acreage, and the cost of soybean seed, as a percent of gross income, was 10.7%, well above the historic range of 4% to 8%. By 2001, conventional and GE seed costs per acre were $19.53 and $26.08 respectively, or 11.3% and 15% percent of gross soybean income per acre.

In 2009, conventional soybean seed cost $41.56 and GE seed $61.17 per acre. Farmers purchasing RR 2 soybeans in 2010 paid about $84.00 per acre for seed, an expenditure equivalent to 22.5% of gross crop income per acre. In that year, GE-HT seed expenditures took a much larger slice out of the gross income "pie" than in recent years.

"All soybean" seed expenditures fluctuated between 13% and 23% of operating costs in the pre-GE seed era (through 1996), and has since rose to around 50% of operating costs per acre – more than double their historic share.

Seed expenditures as a percent of net soybean crop income are also following a precipitous upward trajectory for U.S. soybean farmers. From 1975 through 1997, seed costs per acre accounted for 4% to 13% of net crop income per acre. Conventional seed costs per acre ranged from 11% to 21% from 1998 through 2010, while biotech seeds accounted for 17% to 29% of net farm income.

<u>Corn</u> Corn farmers spent between 4% and 11% of gross income per acre on seed from 1975 through 1996. For farmers purchasing conventional seeds from 2001 through 2010, seed costs ranged from 7% to 11% of gross income per acre, while farmers planting GE seeds spent the equivalent of 10% to 19% on seed.

All corn seed costs accounted for 12% to 15% of corn operating costs per acre from 1975 through 1996, and 7% to 20% of net corn crop income per acre (except for 1986, a year when low prices drove down net returns per acre to far below the historic norm). From 1997 through 2010, conventional seed expenditures were 14% to 20% of operating costs per acre, just slightly above the historic norm. The cost of biotech seed, on the other hand, rose to represent 23% to 34% of operating costs per acre.

Since 2001, conventional corn seed costs per acre have accounted for 11% to 31% of net crop income, and biotech seed costs have ranged from 17% to 44%.

The weather, demand for corn in China, and the growing share of corn production destined for biofuels have driven corn prices higher in the U.S. and around the world. Higher prices have helped farmers absorb rising seed, fertilizer, and fuel costs. Inevitably, corn production and stocks will recover and prices will fall back toward historic norms, or at least part way toward them. The reduction in gross and net income per acre of corn could be significant for many farmers, and will draw closer attention to input costs.

Tighter profit margins, coupled with slipping performance and efficacy of GE seeds, will surely cause some farmers to take a closer look at alternatives. In the absence of a decision across the seed industry to reduce the production of GE seed as a percentage of total seed production, some farmers interested in non-GE alternatives will have nowhere to turn.

Based on a continuation of recent U.S. trends in corn and soybean yields, production costs, and gross and net income, the introduction of GE seeds, and the rising costs of weed management, will result in the transfer to the biotechnology-seed-pesticide industry of between 15% and 30% of the farmer's typical, average long-run net income per acre. A transfer of this magnitude is of historical significance. It will strengthen the ability of the industry to drive the direction of innovation and invest in supportive government and regulatory policies.

It is impossible to predict how the many dynamic forces impacting GE-HT crop yields, costs, and income will impact the economic performance of EU maize, soya, and sugar-beet farms. But the general contours of impact that are now clearly evident in the U.S. will likely emerge in the EU, especially if GE-HT technology is approved without restrictions and adopted as rapidly and widely as in the U.S.

Competition, or lack thereof, in the seed-biotechnology sector will have a significant impact on the farmer's choice of crop varieties, herbicide choice, and seed price premiums. If only one herbicide-tolerant trait is approved in a country, farmers will likely pay higher premiums for cultivars including the trait. If GE seeds come to dominate the market, the supply of non-GE seed will decline, and farmers will often have a hard time finding non-GE versions of the highest-yielding genetics suited to their soils and climate.

VI. Findings, Conclusions, and Implications

Herbicide use projections from 2012 through 2025 have been made for three crops – maize, soya, and sugar beets -- in 27 EU countries from a 2011 baseline. Three scenarios were modeled.

Scenario 1 assumes that the EU does not approve current generation, or any other herbicide-tolerant crops, and reflects a continuation of the weed-management status quo.

Scenario 2 reflects unrestricted approval of RR, glyphosate-tolerant maize, soya, and sugar beets, and furthermore assumes that EU farmers adopt and use the technology on trajectories similar to those in the U.S. from 1996 through 2011.

Scenario 3 is based on targeted adoption of HT varieties, coupled with mandatory resistance-management practices. It represents the pace of adoption and likely patterns of herbicide use if decision-makers and farmers in the EU strive to avoid GR weed problems.

A brief summary of the methodology follows (see Chapter 3 for more detail). Data from Eurostat were drawn upon in establishing year 2011, baseline hectares planted to maize, soya, and sugar beet crops in 27 EU member nations. Recent trends in hectares planted were taken into account in projecting the hectares likely to be planted to each of the three crops through 2025.

Herbicide use data from a variety of sources were integrated in developing 2011 baseline levels of glyphosate use per ha planted by crop and country, as well as the kg/ha applied of other (non-glyphosate) herbicides, and total herbicides. In some EU member states, very modest land areas are planted to maize, soya, or sugar beets, and for this reason, herbicide use on such crops is not addressed via government surveys, or academic or industry research. In such cases, the herbicide use baselines are assumed to be the same as in nearby index countries in which a significant number of hectares are planted. Index countries have been chosen in each of the major agro-climatic regions of the EU, and were summarized earlier in Table 3.1.

Projections of changes in herbicide use from baseline levels were made for 2012-2025 for each crop and index country, and then applied to other countries in the region lacking sufficient data to establish baselines. The parameters projected were:

- Percent hectares of maize, soya, and sugar beets treated with glyphosate;
- Percent hectares treated with a distinct herbicide active ingredient other than glyphosate (“Other Herbicides”);

- Average rate of application per crop year of glyphosate active ingredient, taking into account both the average one-time rate of application and the average number of applications; and
- Average rate of application per crop year of “Other Herbicides.”

These parameters, coupled with the hectares planted each year to the three GE crops studied herein, make it possible to project the kilograms of herbicides applied from 2012 through 2025, across the three scenarios outlined above.

A. Herbicide-Tolerant Crop Impacts on Herbicide Use

Tables 6.1, 6.2, and 6.3 present herbicide-use projections under the three scenarios, and Table 6.4 reports results across the three potential RR crops. Each table contains the same basic information in each of the three scenarios:

- Thousand kilograms applied of glyphosate, “Other Herbicides” (i.e., any herbicide other than glyphosate), and “Total Herbicides,
- Baseline amounts of herbicides applied in 2011, aggregated across the 27 EU countries,
- Projections of use in 2015, 2020, 2025, and
- Changes in herbicide use from the baseline level through 2025.

Maize

Baseline maize herbicide use in Scenario 1 is 16.6 kilotonnes (kt) across the 14.6 million ha planted in the EU in 2011, resulting in an average rate of 1.14 kg/ha. It is projected to rise modestly to 18.8 kt by 2025. Glyphosate use accounts for 12% of total herbicide use in 2011, a share that rises to 22% in 2025. Expansion of the percent of maize hectares planted using no-till or other conservation systems will likely drive the projected increase in glyphosate use in scenario 1.

Overall maize herbicide use rises 13% across the EU in Scenario 1. Several factors will push use trends in different directions. First, rates will trend lower because of the long-standing effort by industry to discover and register low to moderate-dose herbicides. In addition, regulatory actions targeting older, higher-risk and higher-rate herbicides tend to push average application rates of “Other Herbicides” downward. The EU “Sustainable Pesticide Use” Directive is also expected to encourage farmers to both switch to lower dose products and lessen dependence on herbicides via more prevention-oriented farming practices.

But other factors will likely drive average maize herbicide rates upward between 2011 and 2025. In particular, there are large increases in herbicide use projected in countries like Romania, where farmers applied relatively little herbicide in the 2011 baseline. Just 84% of maize in Romania was treated with an herbicide in 2011, at an average rate per crop year of 0.45 kg/ha. By 2025 under Scenario 1, the average hectare is likely to be sprayed with 1.8 herbicides, more than doubling total herbicide use. Despite this relatively rapid, projected rate of growth in maize herbicide use in Romania, the average U.K. or German maize producer would still apply much more herbicide in 2025 under Scenario 1. The average U.K. maize farmer in 2025 would apply 2.2 herbicides per ha at an average rate of 1.04 kg/ha. The average maize farmer in Germany would spray 4 herbicides/ha in 2025 at a rate of 1.9 kg/ha.

A second factor is likely to come into play and will drive rates incrementally higher. The EU member states with the greatest potential to markedly expand corn production are those that are currently applying relatively few herbicides per hectare. If and as world grain prices rise, maize production is bound to grow across the EU, but even more so in countries like Romania, Hungary, and Spain with climates conducive to maize.

Under Scenario 2, total herbicide use doubles from 2011 through 2025, with increasing applications of glyphosate accounting for the increase. There is a projected 1,040% increase in glyphosate use, which rises from 2.0 kt in 2011 to 22.5 kt in 2025. Heavy reliance on glyphosate for weed control, however, makes it possible for farmers to forego applying other herbicides, especially in the early years of adoption before resistant weeds become widely established. The volume of "Other Herbicides" applied falls 27% incrementally through 2025.

Table 6.1 Herbicide Use on Maize in Three Scenarios in the EU (tonnes)

	2011 Baseline	**2015**	**2020**	**2025**	**Change 2011-2025**
Maize					
Scenario 1: No GE Crops					
Glyphosate	1,981	2,522	3,326	4,085	106%
Other Herbicides	14,618	14,995	15,131	14,718	1.0%
Total Herbicides	16,599	17,516	18,458	18,803	13%
Scenario 2: Unlimited Adoption					
Glyphosate	1,981	4,317	12,096	22,546	1,040%
Other Herbicides	14,618	14.052	12,377	10,699	-27%
Total Herbicides	16,599	18,370	24,473	33,245	100%
Scenario 3: Targeted Adoption					
Glyphosate	1,981	3,652	7,510	11,803	496%
Other Herbicides	14,618	12,285	11,848	11,056	-24%
Total Herbicides	16,599	15,937	19,358	22,859	38%

In Scenario 3, total herbicide use rises from 16.6 kt in 2011 to 22.9 kt in 2025, again driven by a 496% increase in glyphosate use. While total herbicide use more than doubled in Scenario 2, it rises just 38% in Scenario 3. This 38% increase is about mid-way between Scenarios 1 and 2, and reflects targeted adoption of RR maize varieties, coupled with adherence to resistance-management provisions that prohibit the back-to-back planting of two RR crops. The increase in glyphosate use in Scenario 3 is almost five-times more than in Scenario 1 and about one-half as much as in Scenario 2.

In Scenarios 2 and 3, the adoption of RR maize reduces "Other Herbicide" use the greatest in those countries that were most herbicide-intensive in 2011. In the U.S., this same pattern of impact is evident in NASS data covering major maize-producing States. In Iowa, for example, three non-glyphosate herbicide were applied on the average maize field in 1996, while 1.74 were applied in 2010. The planting of RR maize in Iowa, coupled with the big increase in reliance on glyphosate, made this reduction of 1.25 herbicide applications per ha possible.

In the major maize producing States in the U.S., each hectare treated with glyphosate allowed farmers to reduce the number of other herbicides applied by 1.0 to 1.5 applications. The projections of changes in maize herbicide use in Scenario 2 in EU countries through 2020 reflect a similar degree of disproportional impact as reliance on glyphosate increases.

Significant impacts from GR weeds are expected after 2020 in the EU, reflecting the assumption that in will take seven to ten years for GR species to emerge and spread to the point where additional herbicides must be applied to avoid significant impacts on crop yields.

From 2020 to 2025, the likely presence of increasingly hard to manage, GR weeds would force EU farmers to rely on additional herbicides, so "Other Herbicide" use starts to rise from 2020 to 2025 despite continuing increases in the percent of hectares sprayed with glyphosate. In addition, more multiple applications will be necessary and some farmers will increase per ha application rates in an attempt to suppress incrementally more stubborn populations of weeds.

Soya

Compared to maize and sugar beets, soya is a relatively minor crop in the EU. It accounts for just 2.4% of the cropland area devoted to maize, soya, and sugar beets. For every soya hectare in the EU in 2011, there were 37 maize hectares and 4.2 sugar beet hectares planted. Soya herbicide use in the 2011 baseline was 0.42 kt, just a fraction of total maize herbicide applications (16.6 kt in 2011). Approval of RR soya could lead to a shift in hectares from lower-value small grain to soya production.

As shown in Table 6.2, soya herbicide use is projected to fall 12% in Scenario 1 as a result of the ongoing trend toward lower-dose herbicides, coupled with the impact of the "Sustainable Use of Pesticides" Directive from the European Commission. Glyphosate use is limited primarily to pre-plant, burn-down applications, mostly in conjunction with no-till planting systems, and accounts for just 12% of total soya herbicide use.

By 2025 in Scenario 1, glyphosate use rises 56%, while "Other Herbicide" use falls 21%, resulting in a 12% drop in total herbicide use. By 2025, glyphosate accounts for 21% of total soya herbicide use, rising in step with adoption of reduced tillage planting systems.

In Scenario 2 with unrestricted adoption of RR soya, total herbicide use rises 123%, driven upward largely by the 1470% increase in glyphosate use. In this scenario, over 90% of soya hectares in some countries would be planted to GE RR varieties, and glyphosate would account for 83% of total herbicide use, a level of reliance on a single herbicide active ingredient bound to trigger and spread GR weeds.

Table 6.2 Herbicide Use on Soya in Three Scenarios in the EU (tonnes)

	2011 Baseline	2015	2020	2025	Change 2011-2025
Three Crops					
Scenario 1: No GE Crops					
Glyphosate	50.0	57.5	68.1	77.6	56%
Other Herbicides	371	360	336	294	-21%
Total Herbicides	421	418	404	372	-12%
Scenario 2: Unlimited Adoption					
Glyphosate	50.0	144	429	778	1,470%
Other Herbicides	371	191	180	162	-56%
Total Herbicides	421	335	608	941	123%
Scenario 3: Targeted Adoption					
Glyphosate	50.0	147	253	379	662%
Other Herbicides	371	320	265	296	-20%
Total Herbicides	421	467	518	675	60%

While in Scenario 3 under targeted adoption, the overall increase in herbicide use is estimated at 60%, and is brought about by the 662% increase in glyphosate use. Glyphosate applications would account for 56% of total soya herbicide use, a level of reliance at which disciplined adherence to resistance management provisions might still prevent the emergence and spread of GR weeds.

Sugar Beets

Across the EU, sugar beets accounted for more than one-half of the total volume of herbicides applied to maize in the 2011 baseline, despite being planted on only one-ninth as many hectares. Of the three crops analyzed in this study, sugar beet weed management is by far the most chemical intensive, because so many weeds, over a relatively long growing season, must be managed.

Even without RR varieties (Scenario 1), a significant share of EU sugar beet hectares are sprayed with glyphosate to kill early season weeds. So in Scenarios 2 and 3, the opportunity to plant RR sugar beets would allow an intensification of glyphosate use, but a much smaller percentage increase in its use compared to soya and maize.

In Scenario 1, sugar beet total herbicide use falls from 8.3 kt in 2011 to 5.9 kt in 2025, a 28% decrease. This reduction is brought about by the shift toward lower-dose herbicides, coupled with EU-wide efforts to reduce overall volumes of pesticides applied. Glyphosate accounts for 12% of sugar beet herbicide use in the 2011 baseline, and 27% in 2025.

Under Scenario 2, unlimited adoption of RR sugar beets has a much more modest impact on both glyphosate use and "Total Herbicides Applied." While total herbicides applied more than doubled in Scenario 2 in maize and soya, it rises only 12% in the case of sugar beets. Glyphosate use increases 377%, and in turn allows farmers to reduce the use of "Other Herbicides" by 39%.

Glyphosate accounts for 12% of total use in the 2011 Scenario 2 sugar beet baseline, rising to 52% in 2025 – about the level beyond which sustainable weed-resistance management is likely not feasible under current technology.

In the conditions modeled in Scenario 3, total herbicide use in the production of sugar beets remains nearly constant, falling from 8.3 kt to 8.0 kt. The projected 36% decline in "Other Herbicide" use is matched by the 228% increase in the volume of glyphosate applications. Reliance on glyphosate relative to total herbicides increases from 12% to 42%, a level at which resistance management might remain feasible for many years.

Table 6.3 Herbicide Use on Sugar Beets in Three Scenarios in the EU (tonnes)

	2011 Baseline	2015	2020	2025	Change 2011-2025
<u>**Sugar Beets**</u>					
Scenario 1: No GE Crops					
Glyphosate	1,023	1,167	1,393	1,591	56%
Other Herbicides	7,264	6,416	5,481	4,349	-40%
Total Herbicides	8,287	7,583	6,874	5,940	-28%
Scenario 2: Unlimited Adoption					
Glyphosate	1,023	1,764	3,126	4,882	377%
Other Herbicides	7,264	6,396	5,549	4,437	-39%
Total Herbicides	8,287	8,161	8,675	9,319	12%
Scenario 3: Targeted Adoption					
Glyphosate	1,023	1,504	2,359	3,356	228%
Other Herbicides	7,264	6,468	5,642	4,629	-36%
Total Herbicides	8,287	7,972	8,002	7,985	-4%

Three Crop Impacts

Across the three crops in Scenario 1, total herbicide use is projected to decline by 1% by 2025 as a result of the 88% projected rise in glyphosate use, coupled with a 13% reduction in the volume of "Other Herbicide" applied (see Table 6.4). Glyphosate use accounts for one in 8.3 kg of herbicide applied in 2011, and one in 4.4 kgs in 2025.

Under Scenario 2, unrestricted adoption of the three RR crops across the EU triggers a significant increase in total herbicide use, and a dramatic increase in glyphosate use. Total herbicide use by 2025 rises 72% across the three crops, while the volume of glyphosate applied would likely increase 824%, to a level where glyphosate accounts for 65% of total herbicide use on the three crops.

Such a level of reliance would almost certainly lead to the emergence and spread across the EU of several economically damaging, glyphosate-resistant weeds. It would necessitate incremental increases in both the number of herbicides applied, as well as higher rates and more applications of individual products. The ecological and human health impacts linked to herbicide use would likely rise, as would the number and severity of episodes where herbicide drift and/or volatilization lead to damage to vegetation and trees in farming areas.

With "Targeted Adoption" in Scenario 3, coupled with strict adherence to glyphosate resistance management plans, overall herbicide use rises 25% by 2025, well less than one-half the increase over baseline evident in Scenario 2. Again, a 409% increase in glyphosate use accounts for the projected overall growth in total herbicides applied. By 2025, glyphosate would account for 49% of total herbicides applied across the three crops, well less than the 65% under Scenario 2.

Farmers in the EU would have a good chance of forestalling the spread of GR weeds if careful field monitoring of the presence and spread of resistant-weed phenotypes, coupled with ongoing research on the most effective methods to curtail the spread of resistance, augmented the resistance management efforts in Scenario 3.

Table 6.4 Herbicide Use on Maize, Soya, and Sugar Beets in Three Scenarios in the EU (tonnes)

	2011 Baseline	2015	2020	2025	Change 2011-2025
Three Crops					
Scenario 1: No GE Crops					
Glyphosate	3,053	3,746	4,787	5,754	88%
Other Herbicides	22,254	21,771	20,949	19,361	-13%
Total Herbicides	25,307	25,518	25,736	25,115	-1%
Scenario 2: Unlimited Adoption					
Glyphosate	3,053	6,226	15,650	28,207	824%
Other Herbicides	22,254	20,640	18,106	15,299	-31%
Total Herbicides	25,307	26,866	33,756	43,505	72%
Scenario 3: Targeted Adoption					
Glyphosate	3,053	5,304	10,123	15,538	409%
Other Herbicides	22,254	19,072	17,755	15,980	-28%
Total Herbicides	25,307	24,376	27,877	31,518	25%

B. Reliance on Glyphosate

In the 2011 baseline, glyphosate accounts for about 12% of total herbicide use in maize, soya, and sugar beets across the EU. As a practical matter, there are limits in the growth of glyphosate use in producing these three crops in the absence of RR varieties. In 2025 under Scenario 1, glyphosate accounts for 23% of overall use, as shown in Table 6.5.

Under the "Unlimited Adoption" scenario, however, glyphosate use increases 824% to over 28 kt in 2025 – ***more than total herbicide use in the 2011 baseline.*** Moreover, glyphosate would account for 65% of the total volume of herbicides applied on these three crops, a level of reliance sure to trigger the emergence and rapid spread of glyphosate resistant weeds.

In maize, glyphosate use accounts for only 12% of total herbicide use in 2011, but 68% in 2025 under Scenario 2. The portion of maize hectares planted to RR varieties would vary from 44% in France to around 90% in Germany and several other EU countries. In general, adoption will likely be highest in southern Europe and in countries that are already heavily reliant on herbicide-based weed management systems.

The growth trajectory for RR maize in France is patterned after the State of Wisconsin, where the availability of RR maize increased the area treated with glyphosate by 44% in 2010. In France at baseline, 20% of maize hectares were treated with glyphosate. In 2025 under the "Unlimited Adoption" scenario, 64% of the maize hectares in France would likely be treated with glyphosate (20% at baseline, plus a 44% increase).

Glyphosate use in the production of soya would rise from 12% of total herbicide use to 83% under Scenario 2. In sugar beets, it would rise from 12% to 52% in the "Unlimited Adoption" scenario in 2025.

The 20.6 kt increase in glyphosate use in maize production projected for 2025 in Scenario 2 across the EU accounts for 82% of the total projected increase in glyphosate use in that scenario across all three crops. The enormous increase in glyphosate use in Scenario 2 is driven by three factors.

First, a much higher portion of the hectares planted to each of these crops would likely be planted to RR varieties. RR seeds will cost more than conventional cultivars, and so farmers investing in these seeds will obviously take advantage of their unique attribute by spraying glyphosate herbicides on RR fields.

Table 6.5 Changes in Glyphosate Use in the “No GE Crops” and “Unlimited Adoption” Scenarios (tonnes)

	2011 Baseline	2015	2020	2025	Increase 2011 to 2025
Maize					
Scenario 1: No GE Crops					
Glyphosate	1,981	2,522	3,326	4,085	2,104
Glyphosate Share of Total Herbicide Use	11.9%	14.4%	18.0%	21.7%	
Scenario 2: Unlimited Adoption					
Glyphosate	1,981	4,317	12,096	22,546	20,566
Glyphosate Share of Total Herbicide Use	11.9%	23.5%	49.4%	67.8%	
Soya					
Scenario 1: No GE Crops					
Glyphosate	50.0	57.5	68.1	77.6	27.6
Glyphosate Share of Total Herbicide Use	11.8%	13.8%	16.8%	20.9%	
Scenario 2: Unlimited Adoption					
Glyphosate	50.0	144	429	778	729
Glyphosate Share of Total Herbicide Use	11.8%	43.0%	70.4%	82.7%	
Sugar Beets					
Scenario 1: No GE Crops					
Glyphosate	1,023	1,167	1,393	1,591	568
Glyphosate Share of Total Herbicide Use	12.3%	15.4%	20.3%	26.8%	
Scenario 2: Unlimited Adoption					
Glyphosate	1,023	1,764	3,126	4,882	3,859
Glyphosate Share of Total Herbicide Use	12.3%	21.6%	36%	52.4%	
Three Crops					
Scenario 1: No GE Crops					
Glyphosate	3,053	3,746	4,787	5,754	2,701
Glyphosate Share of Total Herbicide Use	12.1%	14.7%	18.6%	22.9%	
Scenario 2: Unlimited Adoption					
Glyphosate	3,053	6,226	15,650	28,207	25,154
Glyphosate Share of Total Herbicide Use	12.1%	23.2%	46.4%	64.8%	

Second, there will be increases in the average number of glyphosate applications made on hectares planted to RR varieties. In the U.S. for the first few years, farmers often achieved good-to-excellent weed control with a single application of glyphosate, but as changes started to occur in weed community composition, coupled with the early stages of resistance, farmers had to intensify their weed control programs, and most did so by adding a second glyphosate application one month to six weeks after the first application.

Third, farmers will likely incrementally increase glyphosate application rates per hectare, from around 0.9 kg/ha to 1.2 kg/ha. The highest rates will almost certainly occur in sugar beets, and the lowest average rate in soya production.

Upward movement in the average glyphosate rate of application per crop year will be driven by increases in the number of glyphosate applications made per hectare. If the U.S. pattern is replicated in the EU, this factor will account for about two-thirds of the increase in the average glyphosate rate of application per crop year. Increases in the average one-time rate of application will account for the rest.

In U.S. maize, soya, and cotton production, the one-time rate of glyphosate application rose about 25% from 1996 through 2011 (NASS, multiple years). Levels in 1996 fell in the range 0.71-0.76 kg/ha, rising upward incrementally to 0.92 to 0.96 kg/ha in the case of corn and cotton in 2010, and 0.88 kg/ha for soybeans in 2006, the last year USDA surveyed soybean herbicide use.

By contrast, the average number of applications made per hectare planted to a RR variety rose much more prominently. The average number of applications rose 28% in corn, 70% in soybeans, doubled in cotton (NASS multiple years).

C. Changes in "Other Herbicides" Use in the U.S.

Average herbicide use on RR hectares in the U.S. now exceeds by a considerable margin total application rates on non-RR and non-GE fields (Benbrook 2012). In the case of maize, the difference in 2011 was about 0.45 kg/ha, while in soya, the difference was 0.78 kg/ha (Benbrook 2012). These increments in total herbicide applications on herbicide-tolerant hectares, in contrast to non-HT hectares, are clearly sizable, and in 2011 represented an increase in herbicide use intensity on any given hectare of around 20% (Benbrook 2012).

Farmers reliant on RR crop technology in the U.S. apply considerably more herbicide per hectare for two major reasons. First, more applications at incrementally higher rates of glyphosate have been needed to deal with shifts in weeds and resistance.

Second, there have been incremental reductions in the average rate of application for newly registered herbicides other than glyphosate. For example, in the U.S. in 1996, 27% of soybean hectares were treated with pendimethalin at an average rate of 1.1 kg/ha and another 22% were sprayed with trifluralin at a rate of 0.99 kg/ha. The market leader (imazethapyr) was one of the early, low-dose herbicides registered. It was applied to 43% of hectares planted at a rate of 0.07 kg/ha in 1996 (NASS 1997). By 2002 the combined percentage of soybean hectares treated with the above two high-dose herbicides had dropped from 49% to 16% (NASS 2003), and just 5% were treated in 2006 (NASS 2007).

Between 1996 and 2006, the number of soybean herbicides applied in the U.S. at rates below 0.11 kg/ha increased from nine to 17 (NASS, multiple years). As a result, the amount of herbicides applied to conventional crops has steadily fallen since 1996.

In maize production in the U.S. in 1996, the average herbicide other than glyphosate was applied at a rate of 1.3 kg/ha. This value is a weighted average taking into account both herbicide rates and the share of total applications accounted for by each herbicide. In the last USDA survey of corn pesticide use (NASS 2010), the weighted average rate of non-glyphosate herbicides fell to 0.85 kg/ha, about a 34% drop.

This trend toward incrementally lower application rates should be reinforced by the EU "Sustainable Pesticide Use" Directive, and is why the rate per crop year for "Other Herbicides" in maize, soya, and sugar beets is projected to fall 10% to 33% from 2011 through 2025. Larger reductions are expected when the baseline average rate per crop year is relatively high, compared to other countries.

D. Resistance Management – A Global Imperative

The experience with glyphosate resistant weeds in the U.S. stands as a reminder that excessive reliance on any single weed management strategy, and particularly on one herbicide in a predominantly chemical-based system, is likely to prove unsustainable (Mortensen et al. 2012).

Weed scientists are in near-unanimous agreement that reliance on Roundup Ready technology must be reduced in the U.S. in order to avoid premature obsolescence and the loss of glyphosate as an efficacious herbicide alternative (Owen 2011; Mortensen et al. 2012; Duke 2011). A pointed commentary by six academic weed scientists was published in the April-June, 2012 issue of *Weed Science*. The authors ask "Are we as a discipline so committed to maintaining profits for the agrochemical industry that we cannot offer up realistic long-term solutions to this [glyphosate resistant weed] problem?" (Harker et al. 2012).

They go on to note that herbicides are becoming a nonrenewable resource, because no new major herbicide mode of action has been discovered in 20 years. They call for reductions in the frequency of herbicide applications in order to promote resistance management, a highly controversial suggestion since it would cap the market share any one herbicide could command. They close by arguing that –

"Tinkering around the periphery of the glyphosate resistance problem is clearly too little, too late." (Harker et al. 2012)

What is required to prevent glyphosate resistance? Harker et al. (2012) point to the successful prevention of resistance in the case of herbicide-resistant oilseed rape in western Canada. For years, Canadian farmers have had three herbicide-resistant options to choose from – glyphosate, glufosinate, and imidazolinone herbicide resistant varieties. Plus, oilseed rape is typically rotated with other, non-RR crops in order to break plant disease cycles. However, outcrossing has resulted in feral populations of oilseed rape populations resistant to these three herbicides (Hall et al. 2000), and more recently in the U.S. to two herbicides (Schafer et al. 2011). These findings raise concern over the viability of future, herbicide-based weed control programs in oilseed rape.

Many of agriculture's most serious contemporary environmental, pest management, and food safety challenges can be traced to excessive reliance on production inputs or technology that, when first introduced, appears to offer clear-cut advantages. Rapid and widespread adoption often follows, triggering changes in the ecology of farming systems and the flow of inputs and nutrients within them. Outcomes from such changes include resistant weeds and insects, pollution of streams and drinking water, pesticide residues in food and beverages, and flushes of pathogenic organisms that thrive in the presence of excess nutrients.

Ecologically-based weed scientists argue that skillful integration of "many little hammers" is the surest path to profitable and sustainable weed management. Yet for farmers stretched to cope with multiple, early season tasks, it will remain tempting to reach for one big, effective hammer when there is a chance to do so. This is why managing weed resistance depends on managing behaviors, and remains so elusive a goal.

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Appendix A. The Seed Price Premium-Farm Income Database

A database was compiled in order to track trends in the price of conventional, genetically engineered (GE), and organic corn, soybean, and cotton seed per bag or unit and per planted acre in the U.S., as well as to place expenditures on different types of seed in perspective relative to gross and net farm income, and farm production expenses.

The database runs from 1975, the first year for which USDA reports seed prices, through forecasted values for 2010. In 2001, the USDA began reporting average prices for conventional and biotech corn, soybean, and cotton seeds separately.

A section of the database covers each of the three primary GE crops: corn, soybeans, and cotton. The data elements within each of these sections are similar.

Seed Prices per Bag/Unit/CWT

Average annual seed prices per bag or "unit" for "all seeds" are recorded from 1975 to 2009, and are from the National Agricultural Statistics Service (NASS) agricultural prices reports or industry reports. Prices in 2010 are forecasted and/or are based on industry reports and recent trends.

In the case of corn, a bag/unit of seed contains approximately 80,000 seeds. For soybeans, seed is typically sold by the bushel, and so a bag, or unit, contains about 60 pounds of seed, or about 150,000 seeds, based on an average of 2,500 seeds per pound. Cottonseed is sold per hundred pound unit, so prices are reported per one-hundred weight (CWT). Each CWT contains about 425,000 seeds.

NASS began differentiating the price of "all seeds", conventional seeds, and biotech seeds in 2001. From 2001 through 2010, the database records three different prices per bag/unit/CWT of seed. The 2010 forecasted prices for SmartStax corn and Roundup Ready 2 soybean seed are based on multiple Monsanto announcements regarding 2010 seed pricing.

Seeding Ratings

In order to estimate the costs of seed per acre, it is necessary to calculate the number of acres planted per bag/unit/CWT. The number of seeds planted per acre must be known, or calculated, to determine seed costs per acre.

For most years, the database records the number of seeds per bag, seeds planted per acre, and acres planted per bag. In general, the acres planted per bag/unit/CWT is calculated by dividing the cost of the seed by the seed cost per acre, as reported by the USDA's Economic Research Service (ERS) and described in the next section.

The average number of seeds planted per acre is then calculated by dividing the number of seeds per bag/unit/CWT by the number acres planted per bag/unit/CWT.

Seed Costs per Acre

The average cost of the seeds needed to plant an acre is recorded in the database. Costs per acre for "all seeds", conventional, biotech, and organic seeds are reported. Except for the organic seed prices and the exception noted below, all data comes from the ERS Costs and Returns Data tables.

Data for 2008-2010F in the case of corn, and 2007-2010F for soybeans and cotton, are calculated based on estimated cost of seed per bag/unit/CWT, plus estimated seeding rates.

Crop Production per Acre

Average annual, national crop yields in bushels per acre in the case of corn and soybeans, and hundred-weight for cotton are included in the dataset, and based on NASS's Annual Crop Production Summary. The yield in pounds per acre is calculated by multiplying the number of pounds in a bushel/CWT by the number of bushels/CWT. Next, crop yield per pound of seed is reported and provides a measure of changes in productivity.

Crop Income and Operating Costs

The average annual national prices received per bushel/CWT is then added to the dataset and are derived from NASS's Annual Crop Values Summary through crop year 2009. Prices are assumed to remain unchanged in 2010.

The average gross income from the market per acre is calculated by multiplying the yield per acre by the average price per bushel. The gross value of production as reported by the ERS is listed as a second measure of gross income from crop production. This ERS estimate includes government payments, crop insurance payments, and other incidental payments.

The average operating costs per acre in the database are taken from the ERS Farm Production Cost and Returns data series, with the exception of years 2009-2010 which are forecasted. The net return over operating costs per acre is the difference of the gross income from market minus the operating costs per acre.

Seed Expenditures

Each crop-specific section in the database concludes with various perspectives on the magnitude of conventional, GE, and organic seed expenditures per acre relative to:

- Gross income from the market;
- Average crop operating costs; and
- Net return over operating costs.