Centrum voor Landbouw en Milieu

Agronomic and environmental impacts of the commercial cultivation of glyphosate tolerant soybean in the USA

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Summary

From 1996 to 2000 the acreage of commercial cultivation of glyphosate-tolerant (GT) soybean increased considerably in the USA. Meanwhile public and political debates on agricultural biotechnology in Europe and other parts of the world gained intensity. In the course of time numerous studies, reports and articles on the agronomic and environmental benefits and risks of GT-soybean and other genetically modified crops commercially grown in the USA have been published. However reception of this information by different stakeholders in the public debate on agricultural biotechnology did not lead to consensual views on the agronomic and environmental benefits and risks of GT-soybean. In the media controversial discussions continued.

Subsequently, in October 2000 a Working Committee "Impacts on agriculture and environment of commercial cultivation of GMO-crops in the USA: Case glyphosate-tolerant soybean" has been installed. The following stakeholder organizations were represented in the Advisory Committee: Niaba / Dutch Biotechnology Industry Association, Productboards Margarine, Fats and Oils, Grain, Seeds and Pulses and Animal Feed, Vereniging Milieudefensie / Friends of the Earth the Netherlands, Greenpeace Netherlands, Consumer and Biotechnology Foundation and the Netherlands Society for Nature and Environment, Ministry of Agriculture.

The Advisory Committee determined the objectives of the study and the criteria for evaluation of data. Subsequently, the Dutch Center for Agriculture and Environment (CLM) and Schenkelaars Biotechnology Consultancy (SBC) reviewed the literature, independent from the Advisory Committee. This review focussed on the agronomic and environmental consequences of GT-soybean in the USA. Potential human and animal health impacts of consumption of GT-soybean compared to those of conventional (CN) soybeans as well cultivation of soybean in other countries were beyond the scope of the study.

The following conclusions were drsawn from this literature search.

Acreages of glyphosate-tolerant (GT) soybeans in the USA from 1996 to 2000:

1. The GT-soybean acreage in the USA has expanded rapidly. In 1998, three years after its commercial introduction, the acreage on which GT-soybean was grown amounted to at least one third of the total soybean acreage in the USA. Two years later, in 2000, the GT-soybean acreage consisted of more than half of the total soybean acreage in the USA.

Agronomic yields of GT-soybean varieties compared to those of CN-soybean varieties:

2. A notable difference exists between the results collected from commercial cultivation of GT- and CN -soybean and those generated by variety trials with GT- and CN-soybean. Findings from commercial cultivation suggest that adoption of GT-soybean results in an insignificant to a small yield increase, whereas findings from variety trials suggest that there is a small yield drag.

3. The higher yields of GT-soybean estimated from commercial cultivation can be explained by the positive correlation of the adoption of GT-soybean and production factors related to yield. One of those factors could be less effective weed control in CN-soybean varieties in commercially cultivated soybeans compared with the results from variety trials.

4. Several explanations have been proposed for the yield drag of GT-soybean estimated in variety trials. The most plausible explanation appears to be the rush to get GT-soybean varieties on the market. Consequently insufficient backcrosses have been made to capture the entire yield potential in the parent lines.

Usage of glyphosate and other herbicides in the cultivation of GT-soybean compared to CN-soybean:

5. Studies on the amounts of herbicides used in GT-soybean and CN-soybean cultivation in the USA from 1995 to 1998 yield various values ranging from a 7% increase to a 40% decrease of herbicide use in GT-soybean systems compared to CN-soybean cultivation. Analyses by USDA/ERS for 1997 and 1998, based on appropriate statistical methods, show no significant effect to a reduction of 10% in GT-soybean.

6. Reduction of the amounts of herbicides used in GT-soybean cultivation compared to those in CN-soybean cultivation may however not be fully due to adoption of the GT-soybean system. Other factors related to the herbicide use, like soiltype, weed pressure, farmsize, management-style, prices of different herbicide programs, interact with the impact of adoption of GT-soybean.

7. Application of classical herbicides in CN-soybean cultivation partly has been substituted by applying glyphosate in GT-soybean cultivation.

8. Other chemical approaches to weed control like growing conventional (CN) sulfonylurea-tolerant soybean (STS) may theoretically achieve effective control with less than 10% of active ingredient applied per acre compared to CN-soybean. Thus far results from farmers practice show a reduction of 5% only.

Comparison of herbicides used in soybean cultivation by CLM's Environmental Yardstick for Pesticides:

9. The environmental profile of glyphosate compared to that of other herbicides applied in soybean cultivation in the USA is relatively favourable according to CLM's Environmental Yardstick for pesticides. Glyphosate is however not an 'ideal' herbicide, as its use may lead to runoff to surface water and it also may have adverse effects on water-organisms.

Economic surpluses of GT-soybean compared to those of CN-soybean:

10. Studies based on data compiled from commercial cultivation of GT- and CN-soybean hardly indicate significant economic surpluses at the farm-level related to the adoption of GT-soybean. However it is difficult to draw general conclusions on the economic benefits of GT-soybean at the individual farm level. Net economic returns to the grower vary by year and by location, highly depending on factors such as weed density and climate, and management factors.

11. None of the economic impact studies explicitly addressed the issue of potential (negative) 'externalities' associated with GT- as well as CN-soybean cultivation. All studies took Chemical Crop Protection (CCP) as starting point to compare the 'direct' economic benefits associated with substituting the classical chemistry for weed control in CN-soybean cultivation by adopting GT-soybean systems.

Reasons for farmers to adopt GT-soybean:

12. Only limited data are available about the reasons for adoption of GT-soybean by farmers. In interviews farmers mention increased yield through improved weed control as major reason for their choice of GT-soybean. Experts say ease and flexibility of weed control in large-scale cultivation of soybean is the major reason.

Glyphosate-resistant weeds and weed shifts:

13. Two cases of glyphosate-resistant rye grass in Australia and one case of glyphosate-resistant waterhemp in California have been reported due to the use of glyphosate in the cultivation of conventional crops.

14. Significant weed shifts in GT-soybean cultivation due to increased glyphosate usage associated with the large-scale adoption of GT-soybean in the USA have not been observed. There are however indications that in the Midwest maretail, velvet leaf, ragweed and waterhemp may have become more difficult to control by glyphosate usage.

15. No reports have been found on GT-soybean volunteer plants that could not be controlled (in the next crop).

Impact of GT-soybean on energy consumption and carbondioxide production:

16. There are no data available indicate that the GT-soybean system has specifically contributed to the adoption of no-till by US soybean growers and reduction of fossil fuel consumption.

Impact of GT-soybean on biodiversity:

17. At present it is not possible to draw solid conclusions with respect to the impacts on (agro)biodiversity of GT-soybean versus those of CN-soybean. This ismainly due to the lack of baseline data on CN-soybean cultivation and accurate monitoring data on GT-soybean cultivation. But also because of present scientific, social and moral controversy on how to 'appreciate' (scientific) data on changes in (agro)biodiversity.

18. Irreversible effects like entire (agro-)ecosystem disruption or loss of genetic diversity due to GT-soybean adoption have not been reported.

Development of alternative strategies for weed management:

19. Precision weed management, integrated pest management and organic farming may be useful tools for reduction of herbicide use in soybean cultivation. In organic soybean cultivation herbicides are not used at all. The public concern about these techniques is probably less negative compared to geneticcally modified crops.

20. Adoption of precision weed management, integrated pest management practices and organic farming by (soybean) growers in the US at present is very modest, as no (drastic) breakthroughs have been reported.

21. Both precision weed management and integrated pest management may be applied in the cultivation of GT- as well as CN-soybean varieties. Organic farming excludes genetically modified plants.

22. Non-GMO sulfonylurea-tolerant soybean (STS) varieties may be an alternative to GT-soybeans in terms of reduction of the amounts of active ingredient per acre. But the environmental profile of sulfonylurea is less favourable than that of glyphosate according to CLM's Environmental Yardstick for Pesticides.

Introduction

After European authorities had given green light, the first imports of genetically modified, glyphosate-tolerant (GT) soybean from the USA arrived in Europe in 1996. Despite official approval to use GT-soybean ingredients in food and feed, its introduction on European markets fuelled controversial public and political debates about the benefits and risks of GT-soybean to human health and the environment. Ultimately it led to wider discussions on the application of genetic modification in agriculture and food production in general.

When the first shipments of soybean (ingredients) mixed with GT-soybean (ingredients) arrived in The Netherlands in 1996, Monsanto, its developer, claimed that adoption of the GT-soybean system would reduce the use of herbicides in soybean cultivation in the USA up to 30%.

In April 1996 CLM, the Dutch Centre for Agriculture and Environment published a desk study on the sustainability of GT-soybean. Main conclusion was that its application in soybean cultivation the USA might lead to environmental benefits on the short term because fewer amounts of a herbicide having smaller impacts on the environment could be applied. But the environmental benefits could hardly be quantified. Moreover CLM did not expect unacceptable risks to the environment and human health from GT-soybean and the application of glyphosate on the short run. The study however cautioned that long-term impacts on the environment and human health with increasing scale of glyphosate usage were much harder to assess.

From 1996 to 2000 the acreage of commercial cultivation of GT-soybean increased considerably in the USA, while public and political debates on agricultural biotechnology in Europe and other parts of the world gained intensity. In the course of time numerous studies, reports and articles on the agronomic and environmental benefits and risks of GT-soybean and other genetically modified crops commercially grown in the USA have been published. However reception of this information by different stakeholders in the public debate on agricultural biotechnology did not lead to consensual views on the agronomic and environmental benefits and risks of GT-soybean. Controversial discussions (in the media) continued.

Subsequently, in October 2000 a Advisory Committee "Impacts on agriculture and environment of commercial cultivation of GMO-crops in the USA: Case glyphosate-tolerant soybean" has been installed. The following stakeholder organizations were represented in the Advisory Committee: NIABA / Dutch biotechnology industry association, Productboards Margarine, Fats and Oils, Grain, Seeds and Pulses and Animal Feed, Vereniging Milieudefensie / Friends of the Earth the Netherlands, Greenpeace Netherlands and the Netherlands Society for Nature and Environment, Consumer and Biotechnology Foundation and Ministry of Agriculture.

At the meeting of the Working Committee in October 2000 CLM and SBC indicated that the objectives were to exchange information between parties, to collect factual information on the agronomic and environmental consequences of the cultivation of GT-soybean compared to those of conventional (CN) soybean varieties, and to identify possible reasons for differences.

In November 2000 the Working Committee convened for the second time to discuss the following set of research questions proposed by CLM and SBC:

- What has been the acreage on which GT-soybean has been grown in the USA from 1996 to 2000?
- What have been the yields of GT-soybean compared to those of CN-soybean?
- What has been the use of glyphosate and other herbicides and means in GT-soybean cultivation compared to that in the cultivation of CN-soybean varieties?
- What are plausible causes for potential differences between GT- and CN-soybeans regarding yields and usage of herbicides and other means?
- Has GT-soybean led to uncontrollable volunteer plants?
- Has outcrossing from GT-soybean to wild relatives led to uncontrollable weeds or plants disrupting natural ecosystems?
- Have breakthroughs in the development of alternative, more sustainable methods for soybean cultivation occurred?

This set of research questions led to several comments and remarks by the Working Committee, which in turn led to a further refinement of the research questions. The following main (sub) questions resulted from the Working Committee's second meeting:

- What have been the consequences for soil fertility and biodiversity from GT-soybean cultivation?
- What impact has cultivation of GT-soybean had on usage of fossil fuels?
- Has the emergence of glyphosate-resistant weeds been observed in soybean fields? Shifts in weed populations and in dosages and frequencies of herbicide application should be viewed as indicators.

Based on this objectives the Dutch Center for Agriculture and Environment (CLM) and Schenkelaars Biotechnology Consultancy (SBC) reviewed, independent from the Advisory Committee, the literature. This inventory has been focussed on the agronomic and environmental consequences of GT-soybean in the USA. Similar information from GT-soybean cultivation in other countries, among which Argentina, Brazil and Canada, has not been collected. Potential human and animal health impacts of consumption of GT-soybean compared to those of CN-soybeans were also beyond the scope of the inventory.

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Cultivation of soybeans in the USA

Soybean has become one o the most important elements of the diets in the Western World over the past twenty years. Used as a protein additive, binder, oil, and indirectly as animal fodder, there are few complex processed foods that do not make use directly or indirectly of soybean. The United States has long been the world's largest producer (2000: 75 million metric tons), followed by Brazil (34 million metric tons), Argentina (21 million metric tons), and China (15 million metric tons). Japan, the Netherlands, Mexico, and Taiwan are the largest export markets for U.S. soybean. Morocco and India the largest importers of soybean oil, and the former Soviet Union, Canada, Mexico, and the Netherlands of cake and meal.

Soybeans in the USA are mainly cultivated on large-scale farms. Soybeans are planted in he USA in May and early June. It will take 75-80 days, depending on the climate until the soybean plant has fully matured. The crop is ready for harvesting in September and October. In 1997, commercial fertilizer was applied to less than 40 percent of soybean acreage. Unlike other crops, soybean can fix their own nitrogen an require minimal nitrogen fertilizer. Irrigation was used on 4.2 million acres of soybeans in 1997, or 6 percent of total acreage.

The cultivation is highly mechanized. In the USA the Corn Belt and Mississippi Valley are the center of soybean cultivation (Pillsbury & Florin, 1995). Illinois, the heart of the Corn Belt, is one of the major states for soybean production as this state contributes about 17% of the total annual US soybean production. In Illinois corn and soy are the major crops accounting 46% and 45% of the acreage under cultivation respectively (Illinois Department of Agriculture, 2000). Corn and soybeans have similar climatic demands and can be harvested by the same machinery with minor adaptations. The average size of an Illinois farm including hobby farms is about 368 acres. Illinois farmers are generally more than 50 years old. About 39 % of these farmers also hold jobs off the farm and consider farming as their secondary occupation. Family farms still dominate.

1 Acreages of glyphosate-tolerant (GT) soybean in the USA from 1996 to 2000

1.1 Introduction

For the first time, in 1996, soybean exports from the USA to Europe contained glyphosate-tolerant (GT) soybeans. At that time the acreage, on which GT soybean was commercially cultivated, was very modest compared to the total soybean acreage in the USA. The years thereafter the acreage planted with GT-soybean expanded considerably.

1.2 Available data

Table 1 provides an overview of data collected on the expansion of the acreage, on which GT-soybean has been grown in the USA from 1996 to 2000.

Table 1. Acreages of glyphosate-tolerant (GT) soybean varieties in the USA (1996 - 2000): in million hectares and/or percentage of total soybean area in USA

Year	USDA ERS ARMS[1]	Doanes Market Research / MONSANTO[2]	ISAAA[3]	EU COMMISSION[4]
1996		0.4	0.4	0.4
	< 1%		< 1%	< 1%
1997		3.6	3.6	3.64
	17%		13%	13%
1998		10.9	10.2	10.12
	40%		36%	34%
1999		17.0	15.0	15.00
			53%	51%
2000		> 17.0 estimate	16.3	
			54%	

[1] Source: USDA Economic Research Service (1999)
[2] Source: survey by Doanes Market Research Inc. (Monsanto, 2000)
[3] Source: James (1998,1999, 2000)
[4] Source: European Union (2000)

The data in Table 1 are based on two kinds of data sources:

- The first data source consists of calculations by USDA's Economic Research Services (ERS), which are based on data collected from the Agriculture Management Study (ARMS) for 1996, 1997 and 1998. ARMS is USDA's primary tool for data collection of information on a broad range of issues about agricultural resource use and costs, and farm sector financial conditions. Nearly 8,800 farm and ranch operators in the contiguous 48 States provided data for ARMS. Each respondent represents a number of farms of similar size and type. The sample data are expanded according to the appropriate weights to represent all farms in the contiguous 48 States (Somer *et al*, 1995).

- The other data sources are based on a 1999 market research by Doanes Market Research Inc in commission of Monsanto (Monsanto, 2000) and on a compilation by ISAAA (James, 1998, 1999, 2000) of data from estimations by 'industry' and 'independent researchers', which both were not further identified. The data issued by the EU Commission are based on data from ISAAA.

1.3 Discussion

USDA (1999) noted that its own estimates for the adoption of GT-soybean in 1996 and 1998 are between four and nine percentage points higher than industry estimates.

Benbrook (1999) argues that USDA ERS collects data on the acreage of GT-soybean in combination to that of CN-soybean varieties tolerant to herbicides like sulfonylurea and imidazolin. Methodologically it would therefore be impossible to isolate the growth in acres specifically planted to GT-soybean varieties from the USDA ERS data set. In 1998 and 1999 STS-acreage was nonetheless about 10% of the total soybean acreage in the US, while in 1999 STS-acreage comprised approximately 7%.

However the acreage of GT-soybean has expanded rapidly. Adoption of geneticcally modified crops in the US is progressing at a much faster pace than has been the case for other innovations in plant varieties, e.g. hybrids (European Union, 2000). Whether the GT-soybean acreage stabilizes at about 50%, is a matter of dispute, according to Monsanto (2001), but it may be flattening off, as in some regions of the US weed infestation in soybean cultivation is not a major problem.
Also in the view of the American Soybean Association (De Bruyn, 2001), the GT-soybean system is only attractive in regions where there is serious weed pressure in soybean cultivation, whereas in other regions classical chemical weed control in CN-soybean cultivation still can be more profitable from a farmer's point of view.

1.4 Conclusion

- The GT-soybean acreage in the USA has expanded rapidly. In 1998, three years after its commercial introduction, the acreage on which GT-soybean was grown amounted to at least one third of the total soybean acreage in the USA. Two years later, in 2000, the GT-soybean acreage consisted of more than half of the total soybean acreage in the USA.

2 Agronomic yields of GT-soybean varieties compared to those of CN-soybean varieties_

2.1 Introduction

Data on agronomic yields of GT-soybean varieties in comparison to those of CN-soybean varieties have been collected from two different kinds of sources:

- Data collected from commercial cultivation of GT-soybean and CN-soybean varieties in different (farming) regions in the USA. The differentiation in regions differs depending on the study, although there are large similarities.

- Data collected from GT-soybean and CN-soybean variety trials, in which their agronomic performance, including yield, has been measured, taking into account the 'maturity group', to which a soybean variety belongs; soybean out of a higher maturity group have a longer growing season and normally higher yields. In such variety trials different kind of comparisons can be made. Comparison of the average yield of all GT-soybean varieties tested to the average yield of all CN-soybean varieties tested, comparison of the average yield of the top 5 GT-soybean varieties to that of the top 5 CN-soybean varieties, and comparison of the yield of the Top GT-soybean variety to that of the Top CN-soybean variety. It can be argued that the comparison between top varieties is most relevant, as most farmers will probably select the highest-yielding soybean variety to grow.

2.2 Available data

The data of different studies on agronomic yields of GT-soybean compared to those of CN-soybean (within different years and different states) have been summarized[1] in table 2. The studies are from two kind of data sources:

- For the comparison of yields of commercial cultivation of GT-soybean and CN-soybean, ISAAA generated data by compilation of estimations by 'industry' and 'independent researchers', which both were not further identified. The ISAAA (International Service for the Acquisition of Agribiotech Applications) provide information with the goal to contribute to an sustainable agricultural

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[1] Additional data available not summarised in Table 2:

1) Roundup-only out-yielded conventional plots by 5.3 bushels per acres, in: Fawcett, R.S. North Central Weed Science Research Report 1997.
2) There were no differences in yield among herbicide programs, whether glyphosate was applied alone or following PRE herbicides. Soybean yield with two applications of glyphosate averaged 3,020 kg/ha. In sulfonylurea-tolerant soybean, yields were equivalent, whether chlorimuron was applied alone or following PRE herbicides; yields were at 2,500 kg/ha. In CN-soybean, the conventional herbicide programme of SAN582 plus imazaquin Pre fb aciflorefen plus bentazon EPOST yielded 2,770 kg/ha, in: Reddy, K.N and Whiting, K., Weed Control and Economic Comparisons of Glyphosate-Resistant, Sulfonulurea-Tolerant, and Conventional Soybean (Glycine max) Systems

Table 2 Average yield difference percentage GT- to CN-soybean - not available

development. Several agricultural biotechnology companies fund the ISAAA. USDA ERS based its comparisons on statistical analysis of data collected through its ARMS survey (see for methodology paragraph 1.3). The data from Monsanto were reported in a press release. The press release gave no indications about the methodology used to generate the data.

- The data from Oplinger *et al* (1999) result from 40 performance tests based on a total of 5,712 CN-soybean variety trials and 3,067 GT-soybean variety trials. The data from Benbrook (1999) have been compiled from two reports on variety trials in Minnesota and Wisconsin and Nielsen (2000) compiled data from variety trials in eight different states; both authors do not give further indications about the number of trials. The data from the Nebraska University (1999) have been collected through 22 trials with 65 GT-soybean varieties and 59 CN-soybean varieties at in total 9 different locations. The data from the University of Georgia (1999) have been collected by trials with 32 GT-soybean varieties and 68 CN-soybean varieties conducting at 4 different locations. In all these trials GT-soybean varieties received glyphosate to control weed, whereas the CN-soybean varieties had a variety of other herbicides applied for weed control. The data from Benbrook (2001) have been compiled from 9 locations in Illinois, 3 locations in Minnesota and 3 locations in Nebraska.

2.3 Discussion

2.3.1 Commercial cultivation

Based on data from the ARMS survey on the commercial cultivation of GT-and CN-soybean varieties, USDA/ERS (1999) concludes that the adoption of GT-soybean varieties created a very small yield increase.

Also Fernandez-Cornejo (2000) concludes that increases of adoption of GT-soybean varieties have led to significant but relatively small yield increases. Yields increased less than 1% for a 10% increase of adoption from 1996 to 1998, but the yields can vary substantially across years and regions.

USDA/ERS (1999), Benbrook (1999) and Gianessi & Carpenter (2000) point out that it is nearly impossible to attribute yield differences between adopters and non-adopters as observed in the data to adoption of GT-soybean only. Other factors also affect yield, such as farm size, operator education and experience, debt-to-assets ratio, use of marketing product contracts, irrigation, crop price, and use of consultants. According to Benbrook, it is also likely that GT-soybean adopters include a higher percentage of farmers who are active managers covering large acreage. The bigger the farm, the greater the economic value of the flexibility inherent in GT-soybean systems. Adopters may also choose to plant the higher-priced GT-soybean seeds on their better land.

Contrary to these estimates that adoption of GT-soybean has hardly led to yield increases compared to CN-soybean, data from ISAAA (James, 1998) and Monsanto (1999) show significant yield increases of 4.7 to 16% due to the adoption of GT-soybean. Since both of these studies lack detailed information about data collection and calculations, it impossible to compare the results of these studies with other studies.

2.3.2 Variety trials

The results of variety trials also show a wide range of different yields for both GT- and CN-soybean varieties but in general suggest a yield disadvantage of GT-soybean compared to CN-soybean, except the variety trials carred out by the University of Georgia that show a significant yield advantage of GT-soybean varieties.

Oplinger *et al* (1999) conclude that average yields of GT-soybean varieties ranged from 86% to 113% of the average yields of CN-soybean varieties. The five trials where the average yields of GT-soybean varieties exceed the average yield of CN-soybean varieties are either in Illinois or southern Michigan. Averaged across all regions and locations GT-soybean varieties yielded 4% less than the CN-soybean varieties. Benbrook (1999) draws a similar conclusion. In his view, GT-soybean varieties may have a general yield lag of 2 to 2.5% from GT-soybeans compared to conventional varieties.

The most often heard explanation for the yield lag is that the GT-gene has often not been inserted into the most elite soybeanlines (Monsanto, 2001). A more plausible explanation would be that in the rush to get GT-lines on the market, many companies have not made enough backcrosses to capture the entire yield potential in the parent soybeanlines. The GT-soybean varieties are nonetheless commercialized because of the potential weed control benefits. In Canada, the first GT-soybean varieties were registered because of this reason, although they were known to be lower yielding (Powell 1999). Brummer (1999) argues that the breeding in conventional varieties continues and for this reason the geneticcally modified lines will always lag in yield potential behind elite conventional varieties.

Gianessi & Carpenter (2000) argues that most analyses, such as Oplinger *et al* (1999) and Benbrook (1999) ignore the potential weed control benefits of GT-soybeans, as they are based on the results of variety trials only. In conventional soybean fields the yield potential may not be realized due to poor weed control and due to crop injury from herbicides. In weed control trials, weed control programs are compared to their efficacy in controlling weeds, and yields are often recorded. In commercial cultivation farmers generally tend to maximize yield, where researchers ensure that in (university) trials cultivation takes place under standardized conditions, in order to enable comparative studies. Usually these tests are conducted using one variety in order to eliminate variety as a variable. The yield differences in such trials are due to differences in weed control and/or crop injury associated with the different herbicides tested but do not take into account the yield potential of the variety used in the study. Although it is difficult to generalize about the results of these studies, Gianessi concluded that there seems to be no resounding yield advantage or disadvantage.

Finally, some experimental laboratory observations suggest that GT-soybeans might be more susceptible to heat stress than CN-soybean varieties. According to Gertz et al (1999) GT-soybean plants show splitting stems and yield reductions up to 40% under growth conditions of relatively high soil temperatures (45 oC), and about 20% higher lignin levels at normal temperatures (25 oC). In the view of Gertz et al (1999), the addition of the glyphosate-resistance genes might have altered the product distribution in the shikimate pathway, which leads to aromatic amino acids, lignin and several vitamins and other secondary metabolites. However, there are no field data from the USA (and Brazil and Argentina) confirming these laboratory findings. Moreover, Monsanto argues that the research was conducted in growth chambers using environmental conditions that are rarely, if ever, experienced in the field. This included subjecting the seedlings to high day and night temperature regimes for an entire month.

Stem splitting was not observed under more typical temperatures for any of the varieties tested, whether GT or CN. Only at extreme temperatures (44/35 oC for 32 days) differences were noted but results showed unacceptable damage for both CN- and GT-soybean varieties.

Benbrook (2001) suggests two other explanations for the yield drag of GT-soybean varieties. First, in laboratory, greenhouse and field trials early application of glyphosate under conditions of drought stress may delay nitrogen fixation and decrease biomass and nitrogen content in GT-soybean, according to a study by King et al. (2001). Second, the genetic modification may have negatively affected synthesis of aromatic amino acids in GT-soybean. However, no significant changes in amino acid profile in GT-soybean compared to that of CN-soybean have been observed (Kleter et al, 2000).

2.4 Conclusions

- A notable difference exists between the results collected from commercial cultivation of GT- and CN -soybean and those generated by variety trials with GT- and CN-soybean. Findings from commercial cultivation suggest that adoption of GT-soybean results in an insignificant to a small yield increase, whereas findings from variety trials suggest that there is a small yield drag.

- The higher yields of GT-soybean estimated from commercial cultivation can be explained by the positive correlation of the adoption of GT-soybean and production factors related to yield. One of those factors could be less effective weed control in CN-soybean varieties in commercially cultivated soybeans compared with the results from variety trials.

- Several explanations have been proposed for the yield drag of GT-soybean estimated in variety trials. The most plausible explanation appears to be the rush to get GT-soybean varieties on the market. Consequently insufficient backcrosses have been made to capture the entire yield potential in the parent lines.

3 Usage of glyphosate and other herbicides in the cultivation of GT-soybean compared to CN-soybean

3.1 Introduction

In the 1950s and 1960s herbicide use replaced tillage and cultivation practices as a primary means of weed control in soybean cultivation in the USA. At that time, these were primarily pre-emergence herbicides. The use of post-emergence herbicides in soybean cultivation has been rising steadily since the 1980s. In 1994 for example 72% of the soybean acreage was treated, often in combination with pre-emergence herbicides (European Commission, 2000; Gianessi & Carpenter 2000).

These classical herbicides (like trifluralin, pendimethalin, 2,4-D, sethoxydim, alachlor en metolachlor) have a number a drawbacks, like difficult management, risk of crop damage, development of herbicide resistant weeds. Further such herbicides often limit the possibility of crop rotation and they may have more adverse effects on biotic and abiotic components of (agro-)ecosystems. Herbicide residues on food (exceeding tolerance levels) are also a matter of public concern.

When GT-soybean was introduced on the market several advantages were suggested, like a wider window of application, both in terms of stage of growth of soybeans, and effective control of larger weeds, the easier management of weed control and the fact that there is no carry over, thus giving growers more rotation options.

When introducing the GT-soybean on the European market in 1996, Monsanto claimed that their adoption would result in up to a 30% reduction of active ingredients per acre of herbicide applied. Based on a desk study CLM (Bouman & Pak, 1996) concluded that adoption of GT-soybean in the USA might benefit the environment on the short run due to the application of lesser herbicides that are less damaging to the environment. On the long term the consequences were less clear to CLM, as environmental and public health problems could increase, due to more widespread use of glyphosate.

3.2 Available data

Several reports (USDA ERS/ARMS, 1999; Benbrook, 1999, Gianessi & Carpenter, 2000; USDA ERS, 2000; Fernandez-Cornejo & MCBride, 2000) discuss various ways to estimate the use of glyphosate and other herbicides in the cultivation of GT-soybean varieties compared to CN-soybean varieties:

- Conducting statistical analysis of data collected from surveys of sales of herbicides and seeds and from interviews with farmers.
- Conducting side-by-side weed control trials comparing herbicide usage in the cultivation of GT-soybean varieties to that in growing (near-isogenic) CN-soybean varieties.

The data presented in Table 3 basically comply with the first method.

Table 3 Average differences in herbicide usage in GT-soybean compared to CN-soybean

<table>
<tr><th rowspan="2">REGION</th><th rowspan="2">USDA ERS ARMS[1]</th><th colspan="4">USDA ERS Agricultural Outlook[2]</th><th rowspan="2">ISAAA[1]</th><th colspan="2" rowspan="2">SPARKS & MARKETING HORIZONS[4]</th></tr>
<tr><th>Regression</th><th>Same year</th><th>Year to year</th><th></th></tr>
<tr><td></td><td colspan="3">herbicide acre-treatments*</td><td colspan="5">amounts of active ingredients per acre</td></tr>
<tr><td></td><td>1997</td><td>dif. 97-98</td><td>1998</td><td>1997</td><td>Dif. 97-98</td><td>96- 97</td><td>1996</td><td>1997</td></tr>
<tr><td>Heartland</td><td>- 23%</td><td rowspan="5">Reduction (multi-plied by average applica-tion rate by type of herbicide: increase)</td><td rowspan="5">Reduction largely related to Heartland (no reduction active ingredi-ent)</td><td rowspan="5">Reduction largely related to Southern Seaboard (also reduction acre-treatment)</td><td rowspan="5">-10% (also reduction acre-treat-ments)</td><td rowspan="5">- 10 % to - 40 %</td><td rowspan="2">- 18%</td><td rowspan="2">- 7%</td></tr>
<tr><td>Northern Crescent</td><td>- 15%</td></tr>
<tr><td>Mississippi Portland</td><td>-11%</td><td>- 8%</td><td>- 17%</td></tr>
<tr><td>Prairie Gateway</td><td>+ 0.5%</td><td>- 30%</td><td>- 26%</td></tr>
<tr><td>Southern Seaboard</td><td>- 51%</td><td>- 38 %</td><td>-23%</td></tr>
</table>

[1] USDA/ERS ARMS (1999), Fernandez-Cornejo & McBride (2000): * A herbicide acre-treatment is the number of different active ingredients applied per acre times the number of repeat applications. A single treatment containing two ingredients is counted as two acre-treatments as is two treatments containing a single ingredient. The CN category includes acreage planted to all other purchased and homegrown seed. Differences between mean estimates cannot necessarily be attributed to the use of the seed technology since they are influenced by several factors not controlled for, including irrigation, weathers, soils, nutrient and other pest management practices, other cropping practices, operator management, etc.; [2] USDA ERS (2000): [3] James (1998); [4] Monsanto (2000), Monsanto (1998) (See tables in annex I).

The data from ISAAA are based on a compilation of estimations by 'industry' and 'independent researchers', which both were not further identified.

The data from Sparks Companies Inc. and Marketing Horizons Inc. are based on market surveys of sales of herbicides and seeds in the US commissioned by Monsanto (Monsanto 1998, Monsanto, 2000).

The data from USDA ERS are based on information collected by ARMS surveys for the years 1996, 1997 and 1998. To offer several perspectives on estimating change in pesticide use associated with adoption of genetically engineered crops, Heimlich *et al.* (2000) used three statistical methods in the analysis of data collected in 1997 and 1998.

- *Same-year differences:* Compares mean pesticide use between adopters and non-adopters within 1997 and 1998 for a given technology, crop, and region, and applies that average to total acres producing each crop year.

- *Year-to-year differences:* Estimates aggregate differences in pesticide use between 1997 and 1998, based on increased adoption of genetically engineered crops between those 2 years and average total pesticide use by both adopters and non-adopters. Most of the decrease in pesticide use was in GT-soybeans in the Heartland region.

- *Regression analysis:* Estimates differences in pesticide use between 1997 and 1998, with an econometric model controlling for factors other than genetically engineered crop adoption that may affect pesticide use. This statistical approach controlled for differences between adopters and non-adopters, allowing estimation of changes in pesticide use associated with an increase in the adoption of genetically engineered crops between 1997 and 1998. Since average application rates vary across pesticide active ingredients, the net effect if substituting one for another may be an increase or decrease in total pounds used. Using average application rates, the net effect of adopting GT-soybeans is a reduction in acre-treatments but a slight increase in pesticide use (pounds of active ingredients).

3.3 Discussion

Gianessi & Carpenter (2000) note that there is an absence of information regarding the distributions of the exact herbicide program used by soybean growers. The available data are statistical analyses of use of herbicides and the adoption of GT-soybean provided by the USDA and the industry. A further complication is that weed control in CN-soybean cultivation may be based on application of a combination of 'classical' herbicides, such as trifluralin, pendimethalin, 2,4-D, sethoxydim, and alachlor/metolachlor, and/or new 'low-dose' herbicides, such as sulfonylurea and imidazoline. In addition, the category 'CN-soybean varieties' contains the subcategory conventionally bred, herbicide-tolerant soybean, like sulfonylurea-tolerant soybean (STS).

The USDA/ERS (2000) therefor poses that calculating use of herbicides between GT- and CN-soybean is far from simple. For this reason USDA/ERS analysed the data on the use of herbicides with three statistical approaches. Each approach has its own merits and limitations.

For both the same -year and the year difference corrected for other factors influencing herbicide use.

Year to year comparisons do not account for year-to-year changes in weather conditions, pest pressures, and other factors that may affect pesticide use. Thus it is inappropriate to attribute the results to the adoption of GT-soybeans and other genetically engineered crops only. Still, in the view of USDA ERS, the overall downward trend in pesticide application rates on major US crops (ggo and non-ggo crops) from 1996 to 1998 appears to confirm the pesticide-reducing effect of genetically engineered crops. For example, as adoption of GT-soybean varieties increased from 7 to 45%, the average annual rate of glyphosate use increased from 0.17 pounds per acre in 1996 to 0.43 pounds per acre in 1998, whereas all other herbicides combined dropped 1 pound per acre to 0.57 pounds per acre. This translates into a decline of nearly 10% in the overall rate of herbicide use on soybeans during the period. Contrary to the USDA ERS estimate in 1998 of a rate of 1.57 pound of other herbicides applied per acre in CN-soybean cultivation, Benbrook (1999 & 2001) suggests that less than 0.5 pounds of herbicides per acre were applied, whereas on 15 to 20% of the CN-soybean acreage, the rate was under 0.25 pounds (low-dose system); but no further references were given. Based on USDA/ERS data 1998 Benbrook (2001) calculates the amounts of herbicide used in GT-soybean and CN-soybean. He made a more detailed expansion on soybeanvarieties (non-ggo herbicide tolerant soybeans as separate categorie) and tillage systems (distinguish between conventional/conservation tillage and no till production systems. Benbrook calculates that levels of amounts of herbicides applied in

GT-soybean systems were 7% higher than in CN-soybean cultivation (the data of this report are summarised in the annex I). The report does not provide insight into the statistical approaches applied, nor in their limitations. Since the differences between application rates are small in most cases the USDA/ERS (Fernandez-Cornejo, 2001) argues that the differences are not statistically significant (t value about 1.0). The USDA/ERS is reluctant to draw conclusions from comparing means obtained from farm survey data because they are not adequately controlled for other factors affecting adoption. The Benbrook report only partially compensates for these problems by dividing the data by tillage type and region. These attempts to remedy the problems with direct comparison of means are incomplete.

There may be other ways2 to reduce herbicide use. Growers could switch from 'high-dose' classical herbicides to some of the new low-dose chemicals. In the rapport of 1999 Benbrook argues that 0.1 pound of sulfonylurea per acre is required for weed control in cultivation of sulfonylurea-tolerant CN-soybeans (STS) (Benbrook, 1999). Another new low-dose herbicide like sulfentrazone requires about 0.2 pounds per acre in CN-soybean cultivation. In Benbrook's rapport of 2001, he calcualtes that average use in STS systems was 1.1 pound per acre. According to the calculations of Benbrook this was a reduction of 5% compared to classical herbicides. Estimates of the acreage of those (STS) systems in 1998 vary between 5.4% (Benbrook 2001) and 7% (ASA 2001).

According to USDA/ERS (2000), regression models are generally used to estimate small adjustments from small changes in conditions. Normally, changes in application of a technology would be small over a single year. However, between 1997 and 1998, spectacular growth in the use of genetically engineered crops occurred. The adoption rate of GT-soybean increased with 160% between 1997 and 1998. These large changes may be beyond the predictive scope of the model. The USDA argues that differences in amounts of active ingredients used from this analysis (an increased use of herbicide in GT-soybean compared to CN-soybean) could be the result of a shift of the mix of pesticides the farmers use and can use pesticides at lower-than-average application rates. Thus, the actual reduction in pounds of active ingredients may be larger than estimated by multiplying average use by the reduction in acre-treatments. Gianessi & Carpenter (2001) estimated, based on USDA data on usage of agricultural chemicals from 1990 to 1998, that most active ingredients were used once per treated acre in 1998, whereas glyphosate was used on average 1.3 times per acre. Some growers in GT-soybean program made two post-emergence applications, whereas others may have made one post-emergence in combination with a pre-emergence trifluralin or pendimethalin application. In addition, weed populations resistant to many commonly used soybean herbicides had developed to a significant level in the mid 1990s, like for instance in Missouri and Kansas, where herbicide-resistant kochia and waterhemp had infested a sizeable portion of the soybean growing regions. Following the introduction of GT-soybeans, growers had an effective alternative to control these resistant weed populations. As a result, soybean acreage in Missouri and Kansas expanded considerably.

For both other studies of ISAAA and Sparks & Marketing Horizons there is no description about the data collection and calculations. For this reason it is impossible to compare the data of these studies with the data of the USDA.

[2] See also chapter 9: Development of alternative strategies for weed management.

3.4 Conclusions on amounts of herbicides used

- Studies on the amounts of herbicides used in GT-soybean and CN-soybean cultivation in the USA from 1995 to 1998 yield various values ranging from a 7% increase to a 40% decrease of herbicide use in GT-soybean systems compared to CN-soybean cultivation. Analyses by USDA/ERS for 1997 and 1998, based on appropriate statistical methods, show no significant effect to a reduction of 10% in GT-soybean.

- Reduction of the amounts of herbicides used in GT-soybean cultivation compared to those in CN-soybean cultivation may however not be fully due to adoption of the GT-soybean system. Other factors related to the herbicide use, like soiltype, weed pressure, farmsize, management-style, prices of different herbicide programs, interact with the impact of adoption of GT-soybean.

- Application of classical herbicides in CN-soybean cultivation partly has been substituted by applying glyphosate in GT-soybean cultivation.

- Other chemical approaches to weed control like growing conventional (CN) sulfonylurea-tolerant soybean (STS) may theoretically achieve effective control with less than 10% of active ingredient applied per acre compared to CN-soybean. Thus far results from farmers practice show a reduction of 5% only.

3.5 Comparison of herbicides used in soybean cultivation by CLM's Environmental Yardstick for Pesticides

In addition to amounts of active ingredient of a herbicide applied per surface unit, aspects like their toxicity, bio-degradability and persistence in the soil also play a crucial role in the evaluation of the environmental consequences of the commercial cultivation of GT-soybean varieties. For that purpose the environmental profile of herbicides applied in GT- and CN-soybean cultivation has been determined by applying CLM's Environmental Yardstick for Pesticides (Reus & Leendertse, 2000; CLM, 2000). This tool for assessing the environmental impacts of pesticides is based on environmental conditions prevailing in The Netherlands and may therefore not be fully applicable to the situation in the USA. The Yardstick is based on the type of the used active-ingredients and independent from the cultivated crop. The Yardstick derived environment impact points per pound of active ingredient. The estimates calculated by applying this tool are also based on data provided by pesticide manufacturers to the Dutch Pesticides Authority (CTB).

Table 4 Environmental profile of herbicides applied in GT- and CN-soybean cultivation, according to CLM's Environmental Yardstick (CLM, 2000)

ACTIVE INGREDIENT	AREA APPLIED	Number of applications	RATE	TOTAL APPLIED	ENVIRONMENTAL IMPACT POINTS CLM		
	Percentage		Pounds/acre	Million pounds	Water-organisms	Soil-organisms	Leaching spring
Metolachlor	7	1.1	1.87	8.91	59.7	140.5	300.0
Alachlor	3	1.0	2.36	4.50	36.4	7.4	0.1
Glyphosate	28	1.0	0.81	14.92	0.3	0.0	0.1
Pendimethalin	25	1.1	0.95	17.53	148.1	87.2	0.0
Trifluralin	21	1.0	0.88	12.27	14.8	9.7	0.1
Bentazon	11	1.0	0.65	4.74	0.1	0.0	60.0
Clomazone	5	1.0	0.71	2.32	?	?	?
2,4-D	8	1.0	0.39	2.11	0.0	0,0	0,0
Acifluorfen	12	1.0	0.21	1.69	?	?	?
Metribuzin	10	1.0	0.25	1.69	1818.2	110.9	500.0
Imazethapyr*	38	1.0	0.05	1.24	?	?	?
Sethoxydim	7	1.0	0.21	1.03	0.1	0.0	7,000.0
Thifensulfuron-methyl**	-	-	-	-	0	1	10,000

* expected less toxic for water and soil organisms, some leaching is expected.
** herbicide from the group of sulfonylurea.

If herbicide scores above 100 environmental impact points in a certain category, it exceeds the standard for an acceptable risk to the environment. The figures in Table 4 show that most herbicides have relatively low risks to the environment. Some herbicides such as bentazon, metribuzin, sethoxydim and thifensulfurmethyl (a herbicide of the sulfonylurea group) have a high risk of leaching to groundwater. Data for clomazone, acifluorfen and imazethapyr were not available to CLM.

Main conclusion from Table 4 is that glyphosate has a relatively favourable environmental profile compared to that of other herbicides applied in soybean cultivation in the USA. Glyphosate is however not an 'ideal' herbicide, as its use in spring and autumn may lead to leaching to groundwater and it also has some low risks to water-organisms.

Thifensulfuronmethyl, a sulfonylurea herbicide, has no impacts on water life but it may effect soilorganisms. Its environmental profile is less favourable than that of glyphosate due to its higher risk of leaching to groundwater.

Against the background of the rather widespread use of glyphosate by agriculture, municipalities, railways and hobby gardeners in The Netherlands, concerns have also been raised about AMPA, a degradation product of glyphosate. AMPA frequently has been detected in surface waters at limits above those set for drinking water. From an environmental perspective AMPA is considered harmless, while removal of AMPA in the production process of drinking water would be costly. In addition, human health and occupational safety concerns about so-called inert ingredients in certain formulations of glyphosate have also been raised. To the opinion of CTB, human health risks of glyphosate use are (very) low. However the studies, refered by the environmental movement in its criticism on CTB's admission of glyphosate in The Netherlands, suggest that serious harm to human health may be associated with the use of glyphosate. But CTB considers these studies as flawed and expects no adverse impacts, if glyphosate is used in accordance with the legally binding prescriptions. Annex II provides an extensive review of literature on risk and safety evaluations of glyphosate, its metabolites and its formulations, i.e. inert ingredients.

3.6 Conclusions on the use of herbicides

- The environmental profile of glyphosate compared to that of other herbicides applied in soybean cultivation in the USA is relatively favourable according to CLM's Environmental Yardstick for pesticides. Glyphosate is however not an 'ideal' herbicide, as its use may lead to runoff to surface water and it also may have adverse effects on water-organisms.

4 The economic surpluses of GT-soybean compared to those of CN-soybean

4.1 Introduction

Economic surpluses of the adoption of GT-soybean can be estimated for different actors in the production chain of soy and products containing soy ingredients, like the innovator of GT-soybean, seed companies distributing GT-soybean varieties, individual farmers growing GT-soybean varieties, food industry processing GT-soybean ingredients into products distributed by retailers to consumers, etc. Economic surpluses can also be estimated at aggregated macro-economic levels, for example the national economy of the USA or for all soybean farmers in the USA.

To complement such 'direct' economic estimations of surpluses, negative 'externalities', which may result from both the cultivation of GT-and CN-soybean, also need to be given due consideration. Progress in economic analysis of pest control made clear that the productivity effects of synthetic pesticides have been overestimated, as older economic models treated pesticides as direct productive inputs instead of recognizing their true nature as one of several damage preventing factors. Recent theoretical, normative and causal empirical studies concerning pesticide use, suggest that pesticides are overused. According to Zadoks & Waibel (2000), "With the pesticides technology the benefits are privatized whereas a significant part of the costs are *externalized* and thus borne by society at large".

4.2 Available data

All sets of data on the 'direct' economic surpluses at several levels due to GT-soybean adoption, which have been compiled from several sources in Table 5, do *not* take into account potential externalities related to the use of herbicides in soybean cultivation in the USA, whether GT or CN.

The ISAAA (James, 1999) estimates of economic benefits were considered preliminary by the author, as they were based on limited information available at that time. Net economic returns to the grower vary by year and by location, depending on factors such as weed density and more generally the influence of climate and growing conditions on crop performance.

The estimates by USDA ERS are based on information collected by ARMS surveys for the years 1996, 1997 and 1998 (See annex I for more detailed information; see also paragraph 1.2). USDA ERS' program statistically controls for relevant factors

Table 5 - not available

for which there data by using multiple regression in economic models. That is, differences in economic conditions and crop or management practices are held constant so that the effect of adoption can be observed. ERS analysts control for output and input prices, infestation levels, and self-selection. The data of USDA ERS also form the basis for the estimations by Fernandez-Cortejo & McBride (2000) and Falck-Zepada *et al* (1999).

The data from Monsanto (2000) result from market research by Marketing Horizons Inc. and Doanes Market Research. In an advertisement Monsanto calculates on the basis of data from Moschini (1999) that GT-soybean growers save 6.08 to 11.54 US dollar per acre compared to the herbicides costs of CN-soybean growers.

The information for the Leopold Centre study (Duffy, 1999) was gathered in the late fall and early winter of 1998 during personal interviews with approximately 800 Iowa farmers. According to this analysis, Iowa farmers had identical returns in 1998, whether they raised GT- or CN-soybeans.

The estimates of economic impacts of GT-soybean by Benbrook (1999) are based on findings from the GT-and CN-soybean variety trials reported by Oplinger *et al* (1999), as well as on several assumptions on prices of direct inputs and outputs and on the 'technology fee'. Based on a 'technology fee' of 6 dollars per acre the costs of a conventional herbicide program can range from 14 to 25 dollars per acre, a sulfonylurea program can cost between 11 to 28 dollars per acre, whereas a glyphosate program can vary between 16 to 32 dollars per acre (Gianessi & Carpenter, 2000). But these figures depend highly on the rates used, number of applications and combinations of products.

4.3 Discussion

4.3.1 Economic impacts at farm level

ISAAA (James, 1999) makes the general observation that net economic returns to the grower vary by year and by location, depending on factors such as weed density and more generally on the influence of climate and growing conditions on crop performance. The most important differences between the literature sources are based on differences in cost calculations for seed and herbicides and differences in profits. The differences in profits are mainly based on the differences in measured yields of both GT- and CN-soybean as noticed in chapter 2.

For cultivating GT-soybean growers have to pay an extra technology fee of about 6 US dollar per acre. This technology fee is a payment to the innovator of GT-soybean Monsanto. Differences in additional seed costs could be the result of amount of seeds per acre. For example in a so-called narrow-row soybean system a 25% increase in seeding rate is recommended (Herterman *et al*, 1997). Another cause of the differences in additional seed costs is due to the practice of back saving CN-soybean for use as seed the next year. Massey (1998) calculated that farmers with purchase of new seed every other year instead of purchase new seed every year could save up to $ 6,45 in there seedcosts. For GT-soybean back saving soybean is prohibited. Farmers cultivating GT-soy have to sign a contract that prohibits the back saving of soybean for seed for the crop next year.

Herbicide expenditures per acre vary widely across the Midwest and as a function of agronomic practices and field conditions. Most data suggest that those farmers using GT-soybean varieties with greatest success under conditions of relatively low weed pressure, can get by with one application per year and costs somewhat below the average. Oplinger *et al* (1999) and Benbrook (1999) notice that an increasing number of farmers need two applications of glyphosate and one of at least one additional active ingredient. There are little or no herbicide cost-savings on such farms compared to growers planting CN-soybean varieties and using Integrated Weed Management.

A complicating factor are the reductions in price of other herbicides for weed control in soybean cultivation since 1995, when GT-soybeans were commercially introduced in the USA (Benbrook, 1999; 2001, Gianessi & Carpenter, 2000). In general a myriad of price incentives, volume discounts, product guarantees and rebates has made it very difficult to compare the actual costs of herbicide based systems and will continue to harass those making such comparisons at times to come. Gianessi & Carpenter (2000) argue that the assumptions on yield and cost changes and therefore the results of the analysis are extremely sensitive to the values chosen for certain variables, the supply elasticity in particular. The observed differences may therefore be due to factors other than the adoption of GT-soybean varieties.

In the commercial cultivation the data of the AMRS-survey of the USDA-ERS show that in 1997 farmers cultivating GT-soybean had higher net-returns than farmers cultivating CN-soybean. As noticed in the chapter about agronomic yields the USDA/ERS (1999), Benbrook (1999) and Gianessi & Carpenter (2000) point out that it is nearly impossible to attribute yield differences between adopters and non-adopters observed in the data exclusively to adoption of GT-soybean. Many other factors also affect yield, such as farm size, operator education and experience, debt-to-assets ratio, use of marketing product contracts, irrigation, crop price, and use of consultants. The statistical analyses of the USDA-ERS show that the adoption of GT-soybean is positively correlated with other factors that result in higher net-returns. For this reason the USDA-ERS concluded that there is hardly any difference in the economic returns to a soybean grower between GT- and CN-soybean.

4.3.2 Economic impacts at other aggregate levels

For 1996 ISAAA (James, 1998) estimates that adoption of GT-soybean resulted in 12 million US dollar less costs for herbicide usage in total US soybean cultivation, and in 1997 all US soybean growers saved in total about 109 million US dollar.

Falck-Zepeda *et al* (1999) published estimates of the distribution of welfare from the planting of RT-soybean over Monsanto as technology innovator, seed companies, farmers in the USA and the rest of the world. The model applied for these estimates takes into account conditions, where large production cost savings are attributable to an innovation, and where the technology innovators enjoy intellectual property rights (IPR) protection. With this model the estimate was made that all US soybean farmers together captured 796 US million dollar (76%) of the total economic revenues of GT-soybean. Seed companies selling GT-soybean varieties captured 42 million US dollar in total (4%), the technology innovator (Monsanto) 74 million US dollar (7%), whereas the rest of the world would capture 117 million US dollar (9%). However, in an alternative scenario using other (reasonable) values for the supply elasticity, the US farmer would capture 29% of total surplus, US consumers 17% and the rest of the world captured a net surplus of 29%. The innovators would capture 25% of the total economic surplus.

This alternative scenario shows the extreme sensitivity of the models chosen data for input parameters. Both calculations suggest net returns for GT soybean growers, but studies by USDA ERS on net returns per acre due to adoption of GT-soybean all demonstrated that there have been no significant increases compared to growing CN-soybean.

4.4 Conclusions

- Studies based on data compiled from commercial cultivation of GT- and CN-soybean hardly indicate significant economic surpluses at the farm-level related to the adoption of GT-soybean. However it is difficult to draw general conclusions on the economic benefits of GT-soybean at the individual farm level. Net economic returns to the grower vary by year and by location, highly depending on factors such as weed density and climate, and management factors.

- None of the economic impact studies explicitly addressed the issue of potential (negative) 'externalities' associated with GT- as well as CN-soybean cultivation. All studies took Chemical Crop Protection (CCP) as starting point to compare the 'direct' economic benefits associated with substituting the classical chemistry for weed control in CN-soybean cultivation by adopting GT-soybean systems.

5 Reasons for farmers to adopt GT-soybean

5.1 Introduction

Data on the growth of the acreage, on which GT-soybean has been grown from 1996 to 2000, suggest a rapid adoption of a new weed control technology by soybean growers in the USA which is unparalleled in the history of world agriculture (see chapter 1).

There may be several reasons for farmers to switch rapidly to the GT-soybean system, like economic profitability in terms of lower input costs, better crop performance and higher yields. Since the USDA/ERS has found no evidence of significant change in economic profits, following the dramatic increase in GT-soybean adoption, an important reason for farmers to continue with the new technology could be the high(er) flexibility of the GT-soybean system as a management tool for weed control in soybean cultivation.

5.2 Available data

Table 6 presents the results of two studies. The study of the USDA is based on the results of USDA ERS ARMS survey of 1997 (Fernandez-Cornejo & McBride, 2000). The study of the Leopold Centre (Duffy, 1999) is based on interviews of 365 soybean farmers, that grew GT-soybean, in Iowa.

Table 6 Reasons for farmers to adopt GT-soybean

Reason	USDA-ERS	Leopold-Centre
Increased yield through improved weed control	65.2	53
decrease pesticide input costs	19.6	27
increased planting flexibility	6.4	12
adopt more environmentally friendly practices	2.0	-
Other	6.8	3

In 1998 and 1999 the University of Wisconsin (2000) collected data on adoption of GT-soybean and Bt-corn in Wisconsin through a state-wide survey of over 1,400 farmers. In the winter and spring of 2000 a follow-up survey was conducted, in which about 600 of the same respondents were asked about the use of GMO crops in 1999 and their intended use in 2000. This survey shows that farmers planting over 250 acres of soybeans in 1999 were more likely to use GT-soybean varieties than those planting less than 50 acres. Farmers with over 250 acres were also likely to plant a higher percentage of GT-soybeans on their acres, and this group planted almost half of all GT-soybean acres in Wisconsin. Although the differences were relatively small, the survey also suggested that cash grain operations (who sell most of their crops on commodity markets) were more likely than dairy and other livestock farmers to use GT-soybean.

5.3 Discussion

In two studies of the USDA-ERS and the Leopold Centre 'increased flexibility' has been mentioned by only a small percentage of the farmers as reason to adopt the GT-soybean system, whereas more then half of the farmers mentioned increased yields through improved weed control.

However, most studies, based on data compiled from commercial cultivation of GT- and CN-soybean, hardly indicate significant economic surpluses at the farm-level due to the adoption of GT-soybean (see chapter 4). Increased flexibility of the GT-soybean system compared to that of CN-soybean systems is often viewed as one of the main reasons for rapid adoption by farmers (USDA ERS 1999 and 2000; Gianessi & Carpenter, 2000; Duke, 1999), even at the cost of a potential yield drag (Oplinger *et al* 1999). This flexibility is especially for soybeans an advantage since the traditional herbicides used in CN-soybean have disadvantages. Some traditional herbicides are not effective to the entire spectrum of weeds, others are effective but have a negative impact on the soybean crop or the corn grown following the soybean in the next season (Rotteveel, 2001)

Given the fact that GT-soybeans in principle offer few technical or financial economies of scale researchers of the University of Wisconsin (2000) wonder why larger farmers are more inclined to plant GT-soybean varieties. Even though a more complete analysis of the determinants for adoption and de-adoption of these GMO crops in Wisconsin have to be done, the preliminary data suggest that the performance of such crops plays a leading role in the farmer's decision. Marketing concerns and uncertainties due to European and Asian reluctance about purchasing GMO grain and oilseed products appear to be much less important than crop performance variables such as costs and net returns.

An improvement of work conditions or switches to no-tillage practices are not mentioned by farmers as reason for adoption of GT-soybean.

5.4 Conclusions

- Only limited data are available about the reasons for adoption of GT-soybean by farmers. In interviews farmers mention increased yield through improved weed control as major reason for their choice of GT-soybean. Experts say ease and flexibility of weed control in large-scale cultivation of soybean is the major reason.

6 Glyphosate-resistant weeds and weed shifts

6.1 Introduction

Weeds acquiring resistance against herbicides are a worldwide phenomenon. Most herbicide-resistant weed populations have been selected where the same herbicide or herbicides with the same working mechanism have been applied on a continuous basis for multiple years, coupled with decreased use of other non-chemical methods for weed control, particularly cultivation measures (Shaner, 1999).

Since glyphosate is the (main) herbicide applied in GT-soybean cultivation and adopting the GT-soybean system may encourage no-till practices, the issue at stake here is whether this has led or will lead to the emergence of weeds with resistance against glyphosate.

However, weeds do not necessarily have to acquire true resistance, in order to escape control by a herbicide. Shifts occurring in the species composition of weed populations to weed species, which are less sensitive to the herbicide, constitute another mechanism rendering the herbicide less effective. Such weed shifts can be recorded by monitoring the species composition of weed populations in fields where GT-soybean varieties are grown. Other indicators of weed shifts are an increased use of glyphosate and/or an increased use of other herbicides in addition to glyphosate.

Finally, if GT-soybean is grown in rotation with other GT crops, GT-soybean plants may become volunteers in the next crop, which cannot be controlled by applying glyphosate (See also Chapter 8).

6.2 Available data

In Australia two cases of ryegrass that acquired resistances against glyphosate have been reported and in the USA a third case has also been reported in California. In all three cases, the weeds have acquired resistance against glyphosate resulting from its use in fields with conventional crops (Heap, 2000).

VanGessel (2001) recently report indications of resistance tot glyphosate in marestail (horseweed) in the states Delaware, New Jersey and Maryland. The basis of this phenomenon is presently under investigation by the University of Delaware, Syngenta and Monsanto (Monsanto, 2001).

To control waterhemp in some ‘problem fields’ in Iowa and Missouri, increased amounts of glyphosate are applied and/or the timing of application is improved by earlier applying glyphosate when the weeds are smaller (Harzler, 1999).

6.3 Discussion

The GT-soybeansystem is only practiced for a relative short time. The development of resistance for a herbicide normally takes at least ten years (Rotteveel, 2001). Also weeds would probably acquire resistance against glyphosate at slower rates than in the case of many other herbicides (Bradshaw 1997). The mode of action of glyphosate, its chemical structure, its limited metabolism in plants, its pattern of use and its lack of residual activity are reasons often quoted for why glyphosate is unlikely to select for resistance. But paraquat is also a non-residual herbicide, which has been used in orchards, and as a pre-plant knockdown herbicide. Yet 27 weed species have evolved resistance to paraquat. Nonetheless, the most convincing argument that glyphosate has a 'low risk for resistance' is that despite a long history of extensive use only one weed species, *Lollium rigidum*, has evolved glyphosate resistance until now.

Hence, the potential for weeds in GT-soybean cultivation evolving resistance against glyphosate might be very low, but there are concerns that waterhemp might acquire such resistance (Benbrook 1999). If so, this would imply that (part of) the post-emergence weed control by applying glyphosate would no longer be an option. Just like in the case of weed shifts, higher dosages of glyphosate and/or other herbicides would then have to be used for effective weed control. And this would have adverse consequences for the agronomic as well as for the environmental impacts of growing GT-soybean varieties. According to Benbrook (1999), experience in the field in 1999 suggests that the use of glyphosate will rise perhaps 15 to 25% above 1998 in terms of average pounds of glyphosate applied. In 1998 USDA data showed that the average rate per crop per year for glyphosate on soybeans was 0.92 pounds per acre and there were on average 1.3 applications per acre. In 1999, use will trend upward to perhaps 1.6 applications and 1.2 pounds per acre on average. Farmers across the Midwest have reported decreasing efficacy especially in control of velvet leaf and ragweed species. In 1996 and 1997 inadequate control of these weeds after applying 0.75 pounds active ingredient glyphosate per acre has been reported, but good control at a rate of 1.13 pounds per acre. To the opinion of Benbrook, weed shifts are occurring, perhaps rather swiftly.

6.4 Conclusions

- Two cases of glyphosate-resistant rye grass in Australia and one case of glyphosate-resistant waterhemp in California have been reported due to the use of glyphosate in the cultivation of conventional crops.

- Significant weed shifts in GT-soybean cultivation due to increased glyphosate usage associated with the large-scale adoption of GT-soybean in the USA have not been observed. There are however indications that in the Midwest maretail, velvet leaf, ragweed and waterhemp may have become more difficult to control by glyphosate usage.

- No reports have been found on GT-soybean volunteer plants that could not be controlled (in the next crop).

7 Impact of GT-soybean on energy consumption and carbon dioxide production

7.1 Introduction

Adoption of GT-soybean leads to substantial changes in weed control practices in commercial soybean cultivation. Against the background of global warming due to the 'greenhouse effect', the issue here is whether these changes in weed control in GT-soybean bear consequences for energy consumption and carbon dioxide production compared to growing CN-soybean.

Several studies point out that the GT-soybean system facilitates adopting no-till cultivation. According to Monsanto (1999), no-till cultivation would save approximately 32.7 litres of fossil fuel per hectare over conventional tillage, corresponding with a reduction of 43.26 kilograms of carbon released per hectare as carbon dioxide.

Another advantage of no-tillage would be the reduction of oxidation of carbon in the soil and its subsequent release as carbon dioxide into the atmosphere. Kern & Johnson (1993) conclude from no-tillage practiced prior to the introduction of GT-soybean that to the year 2020 an amount of 37 million metric tons of soil organic carbon would be saved by no-tillage in GT-soybean cultivation.

7.2 Available data

Monitoring data have not been found on changes in fossil fuel consumption, neither reports on oxidation of organic carbon in the soil from growing GT-soybean. The adoption of no-till practices in acreage of soybean in the U.S.A. have been grown rapidly since 1990. In 1990 only 3 million acres of soybean where cultivated with no-till practices. In 2000 the adoption of no-till practices in soybean had grown to 21.1 million acres. However the fastest grown of no-till practices was before the introduction of GT-soybean. In 1996, when only a small quantity of GT-soybean was cultivated (less then 1%), already 16.2 million acres of soybean where grown white no-till practices (Core4, 2000). There is no information about the relation between the adoption of no-till practices and the adoption of GT-soybean in the years after 1996 (USDA-ERS, 2001). Monsanto reported that 46% of the acres planted with GT-soybeans were no-till acres. The numbers of Core4 show that in 1998 in the total of the soybean crop (both GT and CN soybean) had been grown to 2/3 of the acreages.

7.3 Discussion

Since no monitoring data on energy consumption and carbon dioxide production are available, changes in the use of fossil fuels and of release of carbon dioxide into the atmosphere due to the adoption of GT-soybean can hardly be determined or quantified.

7.4 Conclusion

- There are no data available confirming that the GT-soybean system has specifically contributed to the adoption of no-till by US soybean growers and reduction of fossil fuel consumption.

8 Impact of GT-soybean on biodiversity

8.1 Introduction

A proper assessment of the impacts of GT-soybean on biodiversity in comparison to those of CN-soybean is methodologically hampered by large differences in views on concepts like 'biodiversity' and 'agro-biodiversity'. Gillisen and Nap (1998) provide an overview of the various views published on (agro)biodiversity, distinguishing views centered around 'ecology', 'resources' and 'genes'. Depending on the case, positive and negative effects on biodiversity of the cultivation of genetically modified (GM) plants are expected in general (Visser *et al.*, 2001). There is however as yet no scientific, social and moral consensus on how to 'measure' impacts on (agro)biodiversity and on how to 'appreciate' impacts measured.

According to Oerlemans *et al* (1999), the following levels of biodiversity in agro-ecosystems can be distinguished:

1) Genetic diversity: the number of different varieties of a crop species grown in an agro-ecosystem.

2) Functional biodiversity: the number of other species useful for agricultural production, like soil (micro-)organisms, pollinating insects and natural enemies of disease and pest organisms.

3) Harmful biodiversity: the number of species that damage agricultural production through causing diseases and pests.

4) Associated biodiversity: the number of species in an agro-ecosystem with no direct relation to the agricultural production such as birds, flora and fauna in borders of a field.

Introduction of genetically modified crops may influence agro-biodiversity in direct and indirect ways. For example, the use of the number of varieties of a crop species, into which the genetic modification has been bred, may have impacts on the genetic diversity of the agro-ecosystem (level 1). The GM crop may also have changed interactions with other species, for instance due to increased toxicity of the GM crop to pollinating insects in the agro-ecosystem (level 2), or root exudates of a GM crop plant may impact soil microbial communities (levels 2 and 3). The GM crop itself could become a problematic weed in a subsequent crop (level 3). Further, indirect effects could result from changes in agricultural practices due the use of the GM crop. Changed weed control strategies might have positive or negative impacts on flora and fauna species at levels 2, 3 and 4.

In addition, impacts on biodiversity outside agro-ecosystems should also be considered. Introgression of the genetic modification from GM crop into (related) wild species could result in the establishment of the novel genetic trait in such wild species with the potential for natural ecosystem disruption. Or the GM crop itself may invade natural habitats for instance due to increased competitiveness compared to wild flora.

A further distinction can be made between reversible and irreversible effects on biodiversity resulting from growing GM crops. Irreversible effects, like disruption of (natural) ecosystems or losses of genetic diversity cannot be repaired. Reversible effects like changes in the numbers of specific flora and fauna species may be mitigated by no longer growing a GM crop or by changing agricultural practices when growing such GM crop.

8.2 Available data

8.2.1 Genetic diversity

Some may argue that addition of the bacterial EPSPS-gene to soybean has enriched the genetic diversity of soybean, whereas others may view this as a contamination of the gene pool of soybean (Gillisen & Nap, 1998).

Since GT-soybeans have been grown on increasingly larger acreages in the USA from 1995 to 2000, it has been a popular misunderstanding that all those GT-soybeans were based on a single GT-soybean 'line'. However, the genetic modification conferring resistance to glyphosate has been bred from a few GT-soybean lines like for example "transformation event GTS 40-3-2" into very many commercially available soybean varieties using conventional breeding techniques. Crossbreeding the GT-gene is a time-consuming process. Not for all CN-soybean varieties a GT-variety is available.

There are however no data available on the number of GT-soybean varieties grown compared to that of CN-soybean varieties in the USA from 1999 and 2000, nor on the number of CN-soybean varieties grown prior to the commercial introduction of GT-soybean. Impacts on the genetic diversity of the soybean agro-ecosystem due to the large-scale adoption of the GT-soybean system are therefore probably not known in great detail.

8.2.2 Functional and associated biodiversity

8.2.2.1 Change of interactions with other species

No reports with data on changed interactions with other species in the agro-ecosystems of GT-soybean compared to those of CN-soybean have been found in literature.

8.2.2.2 Change of agricultural practice

Monsanto (1998) expected that adoption of GT-soybean would facilitate adoption of no-tillage or conservation tillage practices. Application of no-tillage or conservation tillage practices generally reduces erosion due to wind and water, increases the organic matter of the soil, and improves soil structure, soil moisture and soil fertility as well as wildlife habitat. The GT-soybean would therefore also allow soybean cultivation in areas with soils that are sensitive to erosion. However there are no data the no-till practices have been improved as a result of applying GT-soybean (see paragraph 7.2).

Effects of GT-soybean varieties and their corresponding weed management strategies on canopy insects have been studied in Iowa (Buckelew *et al*,2000). Weed management systems that allowed more weed escapes typically had higher insect population densities. However, systems with fewer weeds were seemingly preferred by potato leafhoppers. The finding of this study indicates that although the GT-soybean varieties did not strongly affect insect populations, weed management systems can affect insect populations in soybean cultivation.

Although weed shifts might be occurring due to the increased use of glyphosate associated with the rapid adoption of GT-soybean (and other GT-crops) in the USA, the problem in itself is not unique but goes generally associated with any weed control system in agriculture. Following from a comparison of the environmental profile of glyphosate and other herbicides used in (CN) soybean cultivation, such as imazethapyr, pendimenthalin and trifluralin, one might speculate that the environmental burden of glyphosate is less than that of the other herbicides. Taking Chemical Crop Protection (see paragraph 4.1) with respect to CN- soybean cultivation as reference, this might in principle results in fewer negative impacts of GT-soybean on functional and associated biodiversity.

On the other hand Lotz *et al* (2000) argues that it might be possible that post-emergent weed control in large-scale cultivation of genetic modified herbicide-resistant crops, could lead to additional problems with fungi, thriving on rotting leaves and decaying plant material of weeds within the crop. This would then have impacts on the use of chemical agents to control problems caused by these fungi. Given the environmental burden of most fungicides, this might indirectly impact (agro)biodiversity in a negative way. There are however no data available on (change of) the use of fungicides in GT-soybean cultivation in the US compared to that in CN-soybean cultivation.

Field experiments conducted by the University of Missouri at two locations from 1997 throughout 2000 revealed that GT-soybean receiving glyphosate at recommended rates enhanced root colonization by *Fusarium* compared to conventional or no herbicides (Kremer, *et al.*). Increases in soil *Fusarium* due to glyphosate may be related to a build-up of fungi on roots leading to intensive soil colonization while roots develop in soil. Although soybean yield was not affected by herbicide treatment, potential yield impacts in subsequent seasons due to high soil *Fusarium* populations resulting from continued use of glyphosate would need further investigations. In addition, genetically modified plants may cause imbalances in soil microbial communities through release of unique substances via root exudation and decomposition of plant residues. The study therefore argues that ecological risk assessment of GT-soybean should include rhizosphere micro-organisms like fungi and nematodes that are involved in both beneficial and detrimental associations with plants and the environment (see also Lukow *et al*, 2000).

8.2.3 Harmful biodiversity

The GT-soybean plant itself may also become a weed in the next crop if this crop is also tolerant to glyphosate (Duke, 1999). But cultivated soybean seed rarely displays any dormancy characteristics and only under certain environmental conditions grows as a volunteer in the year following cultivation (Harvey, 1994). If this should occur, volunteers do not compete well with the succeeding crop, and can easily be controlled mechanically or chemically. The soybean plant is not weedy in its character.

Further, in managed ecosystems, soybean does not effectively compete with other cultivated plants or primary colonizers (OECD[3] 2000).

Moreover, since the commercial introduction of GT-soybean in the USA in 1995, there have been no cases reported about problems of GT-soybean as a troublesome volunteer in the next crop.

8.2.4 Biodiversity outside the soybean agro-ecosystem

Since soybean is a self-pollinator and since weedy or wild relatives of soybean do not exist in the USA there is no risk of outcrossing of the bacterial gene for glyphosate-resistance from GT-soybean to weedy or wild relatives (OECD, 2000). This is probably also the reason why no data on outcrossing of GT-soybean in the USA could be found. Van Dam-Mieres (2001) argues that differentiation of region specified to the presence of wild relatives is not relevant when there are no restrictions on the trade seed. Trade is strongly international orientated. Seed could easily move to an other part of the world.

8.3 Discussion

Against the background of scientific, social and moral debates on how to 'measure' impacts on (agro)biodiversity and on how to 'appreciate' impacts measured, as well as due to the lack of reports with accurate monitoring data on the impacts of GT-soybean on (agro)biodiversity, one can at present only speculate what these impacts might have been, in particular as there are no benchmark or baseline data available of the impacts of CN-soybean cultivation on (agro)biodiversity. Moreover, the issue whether addition of a bacterial GT-gene to soybean has enriched its genetic diversity or has contaminated it cannot be addressed by science.

First, there are no data available on the number of GT-soybean varieties grown compared to that of CN-soybean varieties in the USA from 1999 and 2000, nor on the number of CN-soybean varieties grown prior to the commercial introduction of GT-soybean. But specific impacts of the adoption of GT-soybean on the genetic diversity of soybean agro-ecosystems in the USA are probably very moderate, as the GT-gene has been bred from a few transformation events like "GTS 40-3-2" into many commercially available soybean varieties.

Second, no reports on changed interactions of the GT-soybean plant itself with other species in soybean agro-ecosystems compared to those of CN-soybean plants have been found. Adoption of GT-soybean has neither led to GT-soybean volunteers (harmful biodiversity) in the next crop. Reports of GT-soybean invading natural habitats outside soybean agro-ecosystems – which is highly unlikely due to the biology of soybean (seed) - have not been found, nor data on outcrossing of the genetic modification to wild flora (because soybean has no weedy or wild relatives in the USA).

Third, adoption of GT-soybean has substituted the use of other herbicides with less favourable environmental profiles in soybean cultivation in the USA. It may also have led to an increased adoption of no-tillage or conservation tillage in soybean

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[3] OECD, Draft consensus document on the biology of glycine max (L.) merr. (soybean), Working Group on Harmonization of Regulatory Oversight in Biotechnology, 2000.

cultivation. This in turn might have contributed positively to functional and associated biodiversity in soybean agro-ecosystems in the USA but empirical evidence is lacking.

Fourth, changed agricultural practices due to adoption of GT-soybeans through the application of glyphosate instead of other herbicides might have led to negative and positive changes in insect populations. It might also have led to an increase of harmful biodiversity through root colonization by *Fusarium*. GT-soybean yield was however not affected but continued use of glyphosate in subsequent seasons might result in high *Fusarium* population that would have a potential yield impact.

In summary, adoption of GT-soybeans might have had negative and positive impacts on functional, harmful and associated biodiversity inside and outside soybean agro-ecosystems in the USA but whether these drastically differ from those of CN-soybeans is highly doubtful.

8.4 Conclusions

- At present it is not possible to draw solid conclusions with respect to the impacts on (agro)biodiversity of GT-soybean versus those of CN-soybean. This ismainly due to the lack of baseline data on CN-soybean cultivation and accurate monitoring data on GT-soybean cultivation. But also because of present scientific, social and moral controversy on how to 'appreciate' (scientific) data on changes in (agro)biodiversity.

- Irreversible effects like entire (agro-)ecosystem disruption or loss of genetic diversity due to GT-soybean adoption have not been reported.

9 Development of alternative strategies for weed management

9.1 Introduction

In order to place the agronomic and environmental impacts of the GT-soybean cultivation in the USA from 1996 to 1998 within it's context, this report basically compares the GT-soybean system to conventional weed management strategies based on the application of classical herbicides in CN-soybean cultivation. Next to genetically modified herbicide-resistant crops, other alternative strategies for weed management in cultivation of non-genetically modified CN-soybean are also under development. The issue therefore is whether (drastic) breakthroughs in the development of such alternative weed management systems have occurred, and whether these alternatives would have similar or different agronomic and environmental impacts than weed control based on the GT-soybean system.

9.2 Available data

The most important innovations for alternative weed management strategies generally mentioned in literature include 1) precision weed management; 2) integrated pest management (IPM); 3) breeding of CN-soybean varieties tolerant for a broad-spectrum herbicide; and 4) organic farming.

9.2.1 Precision weed management

Precision weed management is part of the development of precision agriculture. The development of precision agriculture is based on new applications of microelectronics. Herbicides are usually sprayed over an entire area based on the assumption that the weeds will receive the herbicide spray, along with everything else. Microelectronics can be used to support two approaches to precision application of herbicide (Duke, 1997). The first approach is based on the use of satellite based global positioning systems (GPS). GPS mapping of soil types and other factors that might influence required herbicide rates of (soybean) fields has the potential to precisely tailor the application of the herbicide(s). This technology is very suitable for applying pre-emergence or soil-incorporated herbicides. Herbicide spray systems that detect weeds in real time and that direct the herbicide spray only to weeds detected are already on the market in the USA (Houtsma, 1994). Such spraying systems coupled with GPS mapping would have the capability of detecting the weed population in a field, allowing for comparison at different times during the same growing season or from year to year. At present these systems however cannot distinguish between crops and weeds. Research is conducted to use image analysis to identify more than one weed species. Real time weed-detecting spray systems will be especially useful in no-till agriculture, as the farmer can wait for weeds to develop before making the decision to controlling them. In conventional tillage there might be concern about getting into wet fields at the proper time for adequate results with post-emergence herbicides. Duke (1997) argues that precision weed management will have the potential in the nearby future to reduce herbicide use more than any other weed control strategy.

9.2.2 Integrated Pest Management (IPM)

Integrated Pest Management (IPM) utilizes all available pest/weed management tools with a view to achieve economic and sustainable pest management in a crop. To determine all inputs required when applying an IPM strategy in crop production, computer-aided decision making is essential.

In the USA IPM has often only implied an integrated management of insects plagues and other plant pathogens. Insights from weed science used to be neglected in many instances. On the other hand, weed scientists almost always considered only integrated weed management (IWM) in their strategies. Knowledge of interactions between these different management practices of different pest types and weeds is still very limited, and if known, often ignored. For example, pesticides can have profound secondary effects on crops, influencing their resistance, both negatively and positively, to other pests that are not targets of the pesticide (Lydon & Duke, 1993). A great deal of information from the realm of weed biology will be required to achieve truly comprehensive approaches to IPM in crop production (Duke 1997).

9.2.3 Non-genetically modified soybean tolerant for a broad-spectrum herbicide

Sulfonylurea-tolerant soybean (STS) varieties are conventional bred herbicide tolerant soybean. The STS varieties are resistant to certain sulfonylureas, a group of herbicides applied specifically for control of broadleaf weeds. With sulfonylurea herbicides the amount of herbicides applied can be reduced (see chapter 3). STS-soybean varieties have been marketed at the end of the 1980s and 1990s but their commercial success was very modest due to their lesser yields. In 1998 STS-acreage may have been at 10% of the total us soybean acreage, whereas in 1999 it may been about 7% (ASA, 2001).
A handicap of this STS-soybeansystem is that there are 69 weedspecies reported resistance to sulfonylurea herbicides.

9.2.4 Organic farming

Organic farming systems rely on ecologically based practices such as cultural and biological pest management, and virtually exclude the use of synthetic chemicals in crop production and prohibit the use of antibiotics and hormones in livestock production. Under organic farming systems, the fundamental components and natural processes of ecosystems, such as soil organism activities, nutrient cycling, and species distribution and competition, are used to work directly and indirectly as farm management tools. For example, habitat needs for food and shelter are provided for predators and parasites of crop pests, planting and harvesting dates are carefully planned and crops are rotated, and animal and green manures are cycled in organic crop production systems.

For all crop products intended for sale as organic in the USA, the proposed organic crop production standards detail the following (Greene, 2000):

- land would have no prohibited substances applied to it for at least 3 years before the harvest of an organic crop;
- crop rotation would be implemented;
- use of genetic engineering (included in excluded methods), irradiation, and sewage sludge is prohibited;
- soil fertility and crop nutrients would be managed through tillage and cultivation practices, supplemented with animal and crop waste materials and allowed synthetic materials;
- preference would be given to use of organic seeds and other planting stock, but a farmer could use non-organic seeds and planting stock under certain specified conditions;
- crop pests, weeds, and diseases would be controlled primarily through management practices including physical, mechanical, and biological controls; when these practices are not sufficient, a biological, botanical, or allowed synthetic substance may be used.

The Economic Research Service of the USDA (USDA, 2001) estimate of certified organic soybean acreage in the U.S. in 1997 of about 82,000 acres. This is only one-tenth of a percent of U.S. soybean production but a 74 percent grow compared to the private-sector estimate of 47,200 acres for 1995. Expansion of organic soybean acreage was due in part to annual organic soybean prices, which averaged nearly double or more the U.S. cash and nearby futures prices of conventional soybeans between 1995 and 1997. Greater use of specialty markets by organic grain producers might partly explain these price differentials.

While adoption of organic farming systems showed strong gains between 1992 and 1997 and the adoption rate continues high, the overall adoption level is still small. Obstacles to adoption include large managerial costs and risks of shifting to a new way of farming, limited awareness of organic farming systems, lack of marketing and technical infrastructure, inability to capture marketing economies, insufficient numbers of processors and distributors, and limited access to capital. State and private certifier fees for inspections, pesticide residue testing and other services represent an added production expense for organic producers. And farmers can't command certified organic price premiums during the 3-year required conversion period before crops and livestock can be certified as organic (Greene, 2000).

9.3 Discussion

Public concern on the introduction of alternative strategies for weed management is probably less than the negative public concerns about genetic modified corps especially in Europe.

Alternative weed control strategies such as precision weed management based on advanced use of microelectronics, including GPS, and IPM have the potential to effectively reduce usage of herbicides in (soybean) crop production. In organic farming herbicides are not allowed for weed control at all. The level of adoption of these alternative approaches to weed management by soybean growers in the U.S.A. is very modest as yet. Precision weed management and Integrated Pest Management do not necessarily have to compete or replace the GT-soybean system. Both methods may be applied in conjunction with the GT-soybean system.

Non-GMO sulfonylurea-tolerant soybean varieties may require substantially fewer amounts of active ingredient applied per acre than genetically modified GT-soybean. But the environmental profile of sulfonylurea is less favourable compared to that of glyphosate according to CLM's Environmental Yardstick for Pesticides (see paragraph 3.5), as its risk of leaching to groundwater appears to be seriously problematic compared to that of glyphosate.

Organic farming is an alternative that uses no herbicides at all. For this reason GT-soybean in combination with organic farming is not an alternative. Organic farming also excludes genetic modified crops. The acreage of organic soybean cultivation is very low. Enlarging the amount of organically cultivated soybean will have a big impact on the herbicide use. Consequences of organic farm practices are higher production costs due higher labor inputs and lower yields. A point of discussion is wether organic farming may produce suffiecient food for the wordlds growing population when it entirely replaces conventional farming.

9.4 Conclusions

- Precision weed management, integrated pest management and organic farming may be useful tools for reduction of herbicide use in soybean cultivation. In organic soybean cultivation herbicides are not used at all. The public concern about these techniques is probably less negative compared to geneticcally modified crops.

- Adoption of precision weed management, integrated pest management practices and organic farming by (soybean) growers in the US at present is very modest, as no (drastic) breakthroughs have been reported.

- Both precision weed management and integrated pest management may be applied in the cultivation of GT- as well as CN-soybean varieties. Organic farming excludes genetically modified plants.

- Non-GMO sulfonylurea-tolerant soybean (STS) varieties may be an alternative to GT-soybeans in terms of reduction of the amounts of active ingredient per acre. But the environmental profile of sulfonylurea is less favourable than that of glyphosate according to CLM's Environmental Yardstick for Pesticides.

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Annex I Overview of detailed data sets _

Data collected by Monsanto in 1998

REGION	YEAR	AVERAGE GT-SOYBEAN YIELD (Bu/a)		DIFFERENCE
		Monsanto data	USDA ERS data	Monsanto minus USDA
Midwest and Plain states	1998	46.5	41.2	5.3
Southern States		28.4	24.4	4.0
US	1998	43.1	38.6	4.5

Source: Press release Monsanto, St. Louis, 22 January 1999

Data from soybean variety trials in Wisconsin in 1998

REGION	YEAR	COMPARISON	YIELD DIFFERENCE	
			Bu/ac	Percent Yield Drag
Southern Wisconsin	1998	Top GT vs. CN	- 4.7	- 6.2%
		Mean GT vs. CN	-4.4	- 5.9%
		Low GT vs. CN	3.5	- 4.8 %
Minnesota Central Zone	1998	Top GT vs. CN	- 9.3	- 13.1%
Minnesota Southern Zone	1998	Top GT vs. CN	- 2.0	- 2.8%

Source: Compiled by Benbrook Consulting Services, based on the 1998 Wisconsin Soybean Variety Tests, Southern Region, and on the 'Variety Results' by Crookston, Moorhead and Shelly found at http://www.extension.unm.edu/Documents/D/C/Other.

Data from soybean variety trials in Nebraska in 1999

REGION	CN[1]	GT[2]		CN	GT	
	Top 5 average (bu/a)		GT – CN	Mean average (bu/a)		GT – CN
Dixon County	45.7	38.5	- 7.2	39.3	33.3	- 6.0
East Central	65.1	64.9	- 0.1	61.4	60.5	- 0.9
Southeast	67.4	66.3	- 1.1	58.9	57.2	- 1.7
Central Irrigated	66.4	63.7	- 0.7	64.1	59.2	- 4.9
Averages	61.2	58.4	-4.8	55.9	52.6	- 3.4

[1] Conventional soybean varieties

[2] Glyphosate Tolerant soybean varieties

Compiled by SBC and CLM from: Nebraska soybean variety tests 1999, University of Nebraska-Lincoln, Institute of Agricultural and Natural Resources, Agricultural Research Division, Co-operative Extension, EC 99-104-A.

table - not available

table not available

Data from USDA ERS (Agricultural Outlook, August 2000)

Herbicide use difference between adopters of GT-soybean and non-adopters

ESTIMATION METHOD	HERBICIDE USE DIFFERENCE	
	Million acre-treatments	Million pounds active ingredient
Same-year difference 1997	- 5.4	- 0.3
Same-year difference 1998	- 8.9	0
Year-to-year difference, 1997 to 1998	- 7.6	- 6.8
Regression analysis, 1997 to 1998	- 16	2.2

Difference in number of acre-treatments per region = Average of same-year differences in 1997 and 1998 between adopters minus non-adopters

REGION	Difference in number of regional acre-treatments (adopters GE crops minus non-adopters	Percent difference in number of regional acre-treatments (adopters GE crops minus non-adopters	Difference in number of regional acre-treatments (adopters GT soybean minus non-adopters)
Heartland	- 15,152	- 3.9 %	- 5233
Southern Seaboard	- 4,768	- 8.6 %	- 349
Mississippi Portal	- 2,498	- 3.3 %	- 582
Prairie Gateway	- 928	- 2.4 %	0
Northern Crescent	- 1,256	- 2.5 %	- 582
US		**- 3.5 %**	

Herbicide application per treated soybean acre

	1995	**1998**
Total US soybean acreage (millions acre)	62.5	72.3
Percentage treated[1]	97.0	95.0
Acreage treated (millions acre)	60.6	68.7
Number of application acres (millions)[2]	166.0	150.0
Number of herbicide application treatments per acre	2.7	2.2
Aggregate pounds of active ingredient (million)	52	59
Average rate glyphosate (pounds active ingredient per acre)	0.6	0.91
Average rate other herbicides (pounds a.i. per acre)		
Acifluorfen		0.24
Chlorimuron		0.02
Imazethapyr		0.04
Common treatment (pendimethalin + imazethapyr)		1.09

[1] USDA, Agricultural Chemical Usage: Field Crops Summary 1990 – 1998. (Separate Volumes), National Agricultural Statistics Services.

[2] Calculated by Gianessi (2000), assuming that data from the 13 states represent 0.8 of the national total. (Includes pre-plant and on-season use).

Data from USDA ERS (1998)

Major herbicides used on 66.2 million acres of soybean in 19 US states in 1997

ACTIVE INGREDIENT	AREA APPLIED	APPLICATIONS	RATE PER CROP PER YEAR	TOTAL APPLIED
	Percent	Number	Pounds/acre	Million pounds
Metolachlor	7	1.1	1.87	8.91
Alachlor	3	1.0	2.36	4.50
Glyphosate	28	1.0	0.81	14.92
Pendimethalin	25	1.1	0.95	17.53
Trifluralin	21	1.0	0.88	12.27
Bentazon	11	1.0	0.65	4.74
Clomazone	5	1.0	0.71	2.32
2,4-D	8	1.0	0.39	2.11
Acifluorfen	12	1.0	0.21	1.69
Metribuzin	10	1.0	0.25	1.69
Imazethapyr	38	1.0	0.05	1.24
Sethoxydim	7	1.0	0.21	1.03
Total				**78.21**

Fernandez-Cornejo *et al.*, (2000)

Data from Sparks Companies Inc. studies in 1996 and 1997

Herbicide use differences between adopters on GT-soybean and non-adopters

region	1996 (pounds. a.i. per acre)			1997 (pounds. a.i. per acre)		
	CN	GT	Difference	CN	GT	Difference
West Central	0.96	0.79	- 0.17	1.0	0.93	- 0.07
Southeast	1.28	0.79	- 0.49	1.29	0.89	- 0.30
East Central	0.93	0.86	- 0.07	1.07	0.89	- 0.18
Mid-South	1.29	0.89	- 0. 40	1.29	0.96	- 0.33
Average	**1.11**	**0.83**	**- 0.28**	**1.16**	**0.85**	**- 0.31**

Study by Doanes Market Research Company (1999)

Doanes Market Research Company (personal communication Stephen Waters, Monsanto, February 2000) drew the following conclusions from a 1999 study:

1. Introduction of GT-soybeans has resulted in a significant decrease in the cost of herbicides for weed control in soybean. Since 1996, farmgate expenditures for herbicides in soybean have decreased 24%, from 1.66 billion US dollar to 1.26 billion US dollar. Thus all soybean farmers, both GT and conventional soybean growers, have benefited from the introduction of GT-soybeans;
2. There has been a decrease in the use of soil applied, residual herbicides such as Treflan and Pendimethalin, as more and more GT-soybeans are used. These products have largely been replaced by glyphosate. For example, in 1999, 75% of the glyphosate acres (approx. 21 million acres) received only glyphosate application with no residual herbicide application made. Some farmers still choose to apply a soil residual with GT-soybeans, but the trend is toward reducing this use.

Studies collected by Fernandez-Cornejo *et al.* (2000)

Summary of the effects of GT-soybean on yields, pesticide use and returns

RESEARCHERS	DATA SOURCE	YIELD	PESTICIDE USE	RETURNS
Delannay *et al.*, 1995	Experiments	Same	n.a.	n.a.
Roberts *et al.*, 1998	Experiments	Increase	Decrease	Increase
Arnold *et al*, 1998	Experiments	Increase	n.a.	Increase
Marra *et al.*, 1998	Survey	Increase	Decrease	Increase; 6 US dollars per acre

n.a. = not available

- Delannay, X., *et al.*, Yield evaluation of a glyphosate-tolerant soybean line after treatment with glyphosate, Crop Science, 35: 1461 – 1467, 1995.
- Roberts, R.K., *et al.*, Farm-level economic analysis of Roundup Ready Soybeans, Paper presented at the southern Agricultural Economics Association Meeting, Little Rock, Arkansas, February 1 - 4, 1998.
- Arnold, J.C., *et al.*, Roundup Ready programs versus conventional programs: efficacy, varietal performance, and economics, Proceedings of the Southern Weed Science Society, Southern Weed Science Society, 1998, v.51, p. 272 – 273.
- Marra, M., *et al.*, Economic impacts of the first crop biotechnologies, 1998, http://www.ag-econ.ncsu.edu/faculty/marra/firstcrop/img001.gif

Data from Benbrook (2001) based on USDA ERS/ARMS (1998)

Herbicide Use in Fields Planted to Conventional and Herbicide-Tolerant Soybean Varieties in Conventional / Conservation Tillage Production Systems, 1998

	Number Acres Treated (1,000 acres)	Number of Active Ingredients	Pounds Applied Per Acre
Conventional Soybean Varieties	28,340	2.5	1.10
RR Varieties	16,452	1.3	1.14
Other Herbicide-Tolerant Varieties	2,665	2.5	0.97

Source: USDA Economic Research Service Special Tabulation Number 1, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Herbicide Use in Fields Planted to Conventional and Herbicide-Tolerant Soybean Varieties in No-Till Production Systems, 1998

	Number Acres Treated (1,000 acres)	Number of Active Ingredients	Pounds Applied Per Acre
Conventional Soybean Varieties	8,359	3.6	1.27
RR Varieties	9,042	1.7	1.36
Other Herbicide-Tolerant Varieties	888	3.7	1.42

Source: USDA Economic Research Service Special Tabulation Number 1, based on soybean field-level sample data collected as part of the "Agricultural Chemicals Usage" survey (National Agricultural Statistics Service, 1999).

Data from Fernandez-Cornejo (2000) based on USDA ERS/ARMS (1999)
Costs and returns compared by regionin 1997[1] (in US dollars per planted acre).

ITEM	HEARTLAND		MISSISSIPPI PORTAL		SOUTHERN SEABOARD	
	GT	CN	GT	CN	GT	CN
Value production	330.80**	287.88	204.80	225.78	239.63	205.68
Seed[2]	30.03**	17.70	26.78**	14.96	29.43**	15.74
Herbicide	19.20**	28.16	20.61**	28.15	12.54**	24.64
Herbicide application	2.88	3.34	3.57	3.91	2.20	2.83
Weed scouting	0.45	0.29	0.21**	0.60	1.12	0.61
Weed cultivation	0.31**	1.27	0.38*	1.35	0.28	0.49
Total seed & weed costs	52.87	50.75	51.54	48.96	45.56	44.94
Value of production less costs	277.93*	237.12	153.26	176.82	194.07	160.74

** significantly different from all other at the 5-percent level;* significantly different from all other at the percent-level; [1] Statistically compared using a difference of means test. The GT category includes all acreage on which GT-soybeans were planted. The CN category includes acreage planted to all other purchased and homegrown seed. Differences between the mean estimates cannot necessarily be attributed to the use of the seed technology since they are influenced by several other factors not controlled for, including irrigation, weather, soils, nutrient and pest management practices, other cropping practices, operator management, etc.; [2] Includes seed technology fee.

Estimated surplus in million US dollars from GT-soybean in 1997

Seed companies	32 million US dollar	3%
US consumer	42	4%
Technology inventor	74	7%
US farmer	796	76%
Total economic surplus	1,061	100%

Source: Falck-Zepada, Traxler and Nelson, June 1999. Rent creation and distribution from biotechnology innovations: The case of Bt cotton and herbicide tolerant soybeans. Paper presented at Transitions in AgBiotech: Economics of Strategy and Policy, NE-165 Conference, Washington DC.

COSTS OF GT-SOYBEAN SEED AND CN-SOYBEAN SEED

ITEM	**PURCHASE NEW SEED EVERY YEAR (US dollar per acre)**		**PURCHASE NEW SEED EVERY OTHER YEAR**
	CN-seed	GT-seed	CN-seed
Year 1 Seed cost	20.40	20.40	20.40
Year 1 Technology Fee	0	6.00	
Soybeans held for seed	0	0	6.50*
Soybean seed cleaning	0	0	1.00
Year 2 Seed cost	20.40	20.40	0
Year 2 Technology fee	0	6.00	0
Total for 2 years	40.80	52.80	27.90
Annual seed cost	20.40	26.40	13.95

* Decreased sales

Data from Missouri University trials (1998): Massey, R., The focal point – musing of a crop economist; Roundup Ready Seed Economics, University of Missouri, April 1998

Annex II Assessment of glyphosate

Glyphosate is a non-selective systemic herbicide which is absorbed by the foliage and translocated rapidly throughout the plant. The herbicide inhibits 5-enolpyruvulshikimate-3-phosphate synthase (EPSPS), an enzyme of the aromatic acid biosynthetic pathway. This prevents the synthesis of essential aromatic amino acids needed for protein synthesis in plants (Tomlin 1997).

When assessing glyphosate its most important metabolite AMPA (aminomethyl-iphosphonic acid) and different glyphosate formulas are also considered. The different formulas of glyphosate on the market contain surfactants, which are added to improve the penetration of glyphosate.

1.1 Physical properties of glyphosate

When broken down, under both aerobic and anaerobic conditions, the most important metabolite of glyphosate is AMPA. AMPA is further degraded in soil and sediments, producing carbon dioxide. Below we set out the properties of glyphosate and AMPA in air, water and soil.

Behaviour in air
Glyphosate has a very low volatility (negligible to 0.04 mPa) (Tomlin 1997). There are no available data relating to the behaviour and conversion of glyphosate and AMPA in the air (CTB 2000).

Behaviour in water: solubility and degradation
Glyphosate dissolves well in water (11.6 g/l) (Tomlin 1997, CTB 2000) and easily degrades (DT50 = 2 to 5 days). It is broken down less quickly in sediment systems (DT50 = 19 to 45 days) (CTB 2000).

Behaviour in soil: persistence and mobility
Glyphosate and AMPA bind strongly to soil particles and it is generally assumed that they are more or less immobile in soil and do not easily leach away. However, one study indicates that the bonds that tie the pesticide to soil particles can be quickly broken (Cox 1995b, 2000). Based on differing research results, glyphosate has been classified as easily degradable to persistent in soil (DT50 = 4.2 to 49 days) (see Van Rijn *et al.* 1995, CTB 2000, Mensink and Janssen 1994, Eberbach and Daugls, 1983). The metabolite AMPA is poorly to very poorly degradable in soil (DT50 = 74.6 to >90 days). Additional research into AMPA is needed before this may be considered to meet the standard for persistence (Bmb) (CTB 2000; Cox 2000).

1.2 Environmental impacts

1.2.1 Presence in the environment

When Roundup is sprayed on a crop with a field spray some of the compound may be emitted into the surrounding area and not on the crop: into the air through evaporation, into surface water (spray drift) and onto the soil and via the soil into the groundwater.

Air

Pesticides may be transported through the air and dispersed in the environment. Given the fact that glyphosate is almost non-volatile, very little is expected to be emitted to the air. We know of no data on the presence of glyphosate in rainwater.

Soil

Given the high degree of binding to soil particles and a certain degree of persistence, glyphosate and AMPA will be present in the soil for a while after the application of Roundup. How long is not clear because the results of tests of their persistence give differing results. If we use the information from the CTB (Regulatory Board for Pesticides in the Netherlands) we should expect glyphosate to be broken down quite quickly (DT50 = 4.2 to 49 days) and AMPA slowly or very slowly (DT50 = 74.6 to 76.1 days).

Surface water and groundwater

Measurements by water supply companies between 1995 and 1999 indicate that glyphosate is occasionally found in surface water bodies in concentrations above 0.1 µg/l. In general, concentrations of AMPA are considerably higher, to more than 1 µg/l (Puijker and Janssen 1999).

Regarding the origin of glyphosate in surface waters, we can state that untreated rainwater flowing off hard surfaces makes a large contribution. In particular, where rain falls on hard surfaces within a week of the application of glyphosate, high concentrations of glyphosate up to 10 µg/l have been recorded in rainwater runoff. In addition, there are indications that AMPA is formed from other compounds, such as organic phosphonates that are used as stabilizers for cooling water and as additives in detergents (Meerkerk and Puijker 1997, Tielemans and Volz 2000).

RIVM (National Institute for Public Health and the Environment) is the only institute that has conducted research into the presence of glyphosate and AMPA in shallow groundwater under agricultural land on which glyphosate has been applied (Cornelese and Van der Linden, in preparation). Glyphosate was found in one of the nine fields investigated and AMPA in two. The two fields concerned were on sandy soils, one of which received an application of glyphosate in the spring and one in the autumn. In both cases only one of the four mixed samples from the field contained concentrations above the detection limit. This research appears to suggest that there is a certain risk of leaching from sandy soils, but it is difficult to draw any conclusions about the possible seriousness of this because the amounts involved are very close to the detection limits.

In a number of cases in Denmark glyphosate and AMPA have been found in the groundwater. In Roskilde, glyphosate (and AMPA) have even been detected 20 metres deep. This contradicts the view that glyphosate presents no risk to groundwater. The Danish government is investigating the causes and will come to a new decision on the safety of glyphosate at the end of 2001 (Anonymous 2000; Cox 2000).

From the above information it follows that glyphosate, and particularly AMPA, are occasionally found in surface water and shallow groundwater in the Netherlands. Any connection with the agricultural use of Roundup is not clear.

Also in the USA there are data of the incidential presence of glyphosate and/or AMPA in groundwater and surface water (Cox 2000).

1.2.2 Toxicity to organisms in the environment

Plants
Glyphosate is lethal to almost all plants, with the exception, of course, of varieties made specially resistant (CTB 2000).

Micro-organisms
Glyphosate can have a stimulating effect on the release of nitrogen from organic material by moulds and bacteria and on nitrification (formation of nitrate by bacteria) in the soil. Inhibition of nitrification has been observed in a few cases (CTB 2000). Glyphosate has no affect on soil respiration in doses up to 635 mg/kg (CTB 2000).

Fish, crustaceans, algae and water plants
Glyphosate has low to very low acute toxicity to fish, very low toxicity to crustaceans and low to moderate toxicity to algae. Glyphosate has very low chronic toxicity to fish and crustaceans (CTB 2000).
Glyphosate formulas, such as Roundup TX, however, have very high to very low toxicity to algae and water plants; they have high to very low acute toxicity to fishes and moderate chronic toxicity to fish and crustaceans (CTB 2000; Cox 2000).
AMPA has very low toxicity to algae and has very low acute toxicity to fish (CTB 2000).
All applications of glyphosate and AMPA meet the standards for water organisms contained in the Dutch Decree on Environmental Requirements for the Authorization of Pesticides.

Earthworms
Edwards and Bohlen (1996) examined the effects of many agricultural products on earthworms. The authors rank products using a scale from 0 (relatively non-toxic) to 3 (extremely toxic). Glyphosate is ranked 0, indicating a low toxicity to earthworms. This is confirmed by information from CTB indicating a LC 50 of 360 mg/kg for earthworms (CTB 2000). Glyphosate products meet the standard for earthworms as included in the EU Uniform Principles for Evaluation and Authorization of Plant Protection Products.

Beneficial insects and mites
The CTB reports that glyphosate and glyphosate formulas have very low acute toxicity to bees and bumble-bees, but notes that one study does indicate that glyphosate may have a negative effect on bees and bumble-bees. Research also indicates that relevant doses used in the field have no effect on the mortality of ground beetles, but that glyphosate formulas are moderately toxic to some spiders and parasitic wasps and toxic to predatory mites. The standard for non-targeted arthropods in the Uniform Principles, therefore, is not met. Additional semi-field research is needed (CTB 2000).

Birds
Birds may be exposed to glyphosate via food and water. Glyphosate has low acute toxicity to birds (LD50 > 3200 mg/kg). AMPA has low acute toxicity to birds when ingested orally (CTB 2000). In the Netherlands no applications are permitted in which the concentration of glyphosate in seeds and small insects (food) exceed the standards in the Uniform Principles. Neither does exposure via drinking water lead to the standards for birds included in the Uniform Principles being exceeded.

Mammals
Because glyphosate acts on enzymes that are only present in plants, it is expected to have limited toxicity to animals. The CTB (2000) concludes that glyphosate ingested orally has low toxicity to mammals (LD50 > 2000 mg/kg). As in the case of birds, all approved applications meet the standards for food and drinking water contained in the Uniform Principles. Indirect effects on small mammals may occur through disruption of the natural habitat or the disappearance of important sources of food.

Amphibians
Monsanto (1998) has reported on tests with frogs that indicate proper use of their products will not result in toxic effects on these animals. The CTB has not reviewed the results of these tests.

1.2.3 Estimated risks to the environment

When assessing the use of glyphosate a distinction must be made between glyphosate itself, AMPA (the most important metabolite of glyphosate) and various glyphosate formulas. Glyphosate is reasonably degradable and does not leach from soil.

SURFACE WATER
Glyphosate is sometimes found in surface water, occasionally in concentrations exceeding the standard for drinking water of 0.1 µg/l. AMPA is moderately degradable and is often found in surface water, sometimes in concentrations considerably above the standards for drinking water (0.1 µg/l). It is expected that the use of glyphosate on hard surfaces (such as roads) makes a large contribution to the amount of AMPA in surface waters; it is probable that a small proportion found in surface water originates from spray drift. AMPA has little effect on organisms, but is a problem in drinking waiter.

TOXICITY
There are large differences between the different formulas of glyphosate. Some formulas have low toxicity; others are toxic, particularly to water organisms. At high doses, these formulas can cause problems for birds and mammals.

1.3 Effects on human health

Risks to human health are determined by a combination of the toxicity of the compound and exposure to it.

1.3.1 Exposure

Measurements of daily intake of glyphosate via food and drinking water are not available (Mensink and Janssen 1994). The Residue Decree (*Residubeschikking)* under the Pesticides Act sets down residue tolerances per product. These residue tolerances have been adopted by FAO/WHO and are established in the following way. From tests it is established which residues remain after application according to the legal instructions for use.[4] Then the Acceptable Daily Intake (ADI) is used to test whether the residues found present a risk to human health. If this is not the case, the level of residues found is taken to be the residue tolerance. If the residues found do present a danger to human health, the instructions for use have to be amended to ensure that lower residue concentrations remain after application. The residue tolerances finally established will then never be exceeded as a result of normal agricultural use (following the legally established instructions for use).

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[4] In the Netherlands the legal instructions for use for spot applications of glyphosate on various agricultural and horticultural crops grown for human consumption include a safety period of 7 days to 4 weeks (*Gewasbeschermingsgids* 1999). This has an agricultural basis. First, there is no point in controlling weeds with glyphosate less than 4 weeks before harvest, and crop plants exposed by accident to glyphosate will have died within 4 weeks and therefore not harvested with the crop. There will, therefore, be no residues on the harvested crop. Heavily weeded plots of dry crops are sometimes sprayed with glyphosate up to 7 days before harvest to make harvesting easier. The crop itself has by then died and does not take up any of the glyphosate; the 7-day delay is necessary to let the weeds dry out.

The Dutch Residue Decision contains no residue tolerance for soya because this crop is not grown in the Netherlands. As glyphosate is used in a modified form on soya in GT-soya in the US the tolerance has been raised from the detection level to 20 ppm (Monsanto 1999b).

A point worth considering here is that it is not yet possible to obtain reliable measurements of the amount of glyphosate taken up into the plant matrix (as a residue *in* rather than on the surface of the plant).

If the instructions for safe use are followed, people applying glyphosate are not exposed to the compound, or only in negligible quantities (Mensink and Janssen 1994).

Toxicity to humans

Toxicity of pesticides to humans are generally derived from the results of tests on animals because there are very few data on the behaviour of pesticides in humans. Both incidental and long-term exposure and both acute and chronic health effects are taken into account.

The WHO has conducted an extensive review of the literature on the possible effects of glyphosate on people and the environment (Mensink and Janssen 1994). TNO has also carried out research and in 1998 Germany prepared an EU monograph on glyphosate. The last two studies were used by the CTB in their assessment. Based on the various studies that have been conducted, the WHO and the CTB draw the following conclusions:

- Glyphosate and AMPA have low acute toxicity from exposure through ingestion, inhalation or skin contact. In the WHO classification for acute toxicity, glyphosate is classified as a Table 5 compound, one that is unlikely to present any acute danger from normal use.
- Glyphosate is taken up into the body to a certain degree but is almost never metabolized: 99% leaves the body within 7 days. Only 0.5% is converted to AMPA.
- Oral ingestion of large amounts of Roundup is toxic to humans (as are most compounds).
- Roundup has a higher acute toxicity than the active ingredient glyphosate because of the presence of accessory agents in the Roundup formula.
- The results of tests on animals indicate that glyphosate is not a carcinogen, mutagen, teratogen or neurotoxin. The EPA has placed glyphosate in Category E (evidence of non-carcinogenicity for humans).
- Oral exposure has (sub)chronic toxic effects in rats and mice: among the effects found are damage to the liver and changes in the weight of body organs.
- AMPA does not cause irritation of the skin or eyes and is not genotoxic or teratogenic.
- Glyphosate and its associated formulas can cause irritation of the eye and light irritation of the skin, but does not induce oversensitivity. According to Monsanto the new Roundup formulas (Ultra and Dry, without POEA) do not cause any irritation.

In addition to glyphosate and POEA, Roundup contains 1,4-dioxane and N-Nitroglyphosate in extremely low concentrations. Research by Monsanto shows that N-Nitroglyphosate has no negative health effects (Monsanto 1998).

Other literature sources indicate the following effects of glyphosate:

- If injected, glyphosate is acutely toxic. However, it should be noted that such an exposure route is highly improbable under normal use (Cox 1995a, 1998, 2000).
- Formulas containing glyphosate have greater acute toxicity to animals and humans than glyphosate itself: POEA is more toxic than glyphosate and the combination of these two substances is more toxic still. The WHO report also indicates this, but mentions that the toxicity of these formulas is still very low. The WHO also confirms that Roundup is highly toxic to humans if ingested. However, this information is based on cases of attempted suicide and accidental ingestion, situations that represent highly improbably intake routes and involve extremely high doses (Cox 1995a, 1998). Cox (1998) mentions the following symptoms of the intake of large

doses of glyphosate-containing products: eye- and skin irritation, headache, nausea, numbness, elevated blood pressure and heart palpitations.

- According to the WHO and the EPA, feeding studies of rats and mice show that glyphosate is not carcinogenic. According to Cox (1995a, 1998, 2000) this can be challenged because in these studies tumours were found in both rats and mice. However, tumours were also found in the untreated rats and mice, which led the WHO and EPA to conclude that there was no significant link between these tumours and glyphosate. Cox (1995a, 1998, 2000) also comments that no studies have been carried out that test the carcinogenicity of Roundup or other formulas containing glyphosate. This would suggest that no conclusions can be drawn about the carcinogenicity of formulas containing glyphosate. However, it is not standard practice to test different formulas when deciding on the authorization of pesticides for use. Data on acute toxicity, skin irritation, etc. do have to be provided for formulas. For chronic effects, carcinogenicity, etc., data must be provided on the individual ingredients in formulas. If one of these ingredients gives cause for concern, further research is carried out. This has not yet been the case with formulas containing glyphosate (Cox 1995a).
- No genotoxic effects have been observed in any long-term studies in which glyphosate has been fed to laboratory animals. The WHO concludes that glyphosate is non-mutagenic. Cox refers to experiments in which Roundup in fruit flies and human blood cells is said to have caused in vitro mutagenic effects. According to Monsanto various toxicological experts have judged the test methods used in these studies to be insufficient. According to Janssen (personal communication) the results of these experiments offer insufficient reason to review the conclusion on the mutagenicity of glyphosate: the tests do not clearly show which ingredients in Roundup are responsible for the possible effects; the scale of the tests and the effects found are very limited; and it is not clear whether such effects could occur in vivo in mammals (Cox 1995a, 1998, 2000).
- Long-term feeding with glyphosate may well affects growth rate and liver weight in rats. The WHO report mentions this, but comments that the usual exposure levels in humans are so low that they do not present any danger (Cox 1995a).
- There is some controversy about the possible effects of pesticides, including glyphosate, on fertility. Yousef *et al.* (1995) found effects on sperm quality in a study on the effects of glyphosate in food on rabbits. Similar effects in tests on rats carried out earlier are conspicuous by their absence (Mensink and Janssen 1994). In the tests carried out by Yousef *et al.*, the number of test animals was limited and the reporting incomplete. Based on the available information, therefore, we can make no definite statements about any effects glyphosate may have on fertility.
- Although AMPA has a low acute toxicity, it may still cause toxicological problems. This has been shown in sub-chronic research using rats (Cox 1998, 2000).
- Swedish researchers conclude that glyphosate may increase the risk of non-Hodgkin lymphoma. Gene mutations and chromosomal aberrations have been reported in mouse lymphoma cells exposed to glyphosate. Furthermore, the incidence of hepatocellular carcinoma, leukaemia, and lymphoma was somewhat increased in a study on mice. In a culture of human lymphocytes, glyphosate increased the number of sister chromatid exchanges. The researchers also found in a case control study that herbicides (including glyphosate) increase risk of hairy-cell leukaemia, a rare type of non-Hodgkin lymphoma (Hardell and Eriksson 1999, Nordström *et al.* 1998).

Estimated risk to human health

The CTB assessment is that the risks of using glyphosate to human health are low and that proper use according to the legal instructions is not expected to cause any negative effects. A few studies indicate potential risks associated with glyphosate. These results have been picked up by environmental organizations, who say that the risks to public health are greater than generally accepted. The CTB, however, considers the data used by these environmental groups lack a sound basis. Proper use according to the legal instructions is expected to have no or negligible negative effects on human health. Further research is needed only on the risks to the user of manual application of glyphosate in granular form.

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