Inventory of possible crop cultivation changes as a result of the introduction of GM crops in the Maritime zone of Europe

An overview for Maize, Sugar beet and Potato

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Table of contents

Summary

This report is the result of a project answering the following research question formulated by COGEM: what cultivation changes can be expected in the maritime zone of Europe after the possible introduction of the cultivation of GM maize, potato and sugar beet? The research question was in part triggered by EU Directive 2001/18/EC (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:106:0001:0038:EN:PDF) and its interpretation by EFSA (http://www.efsa.europa.eu/en/scdocs/doc/1879.pdf), both demanding full evaluation of possible changes resulting from the introduction of GM crops, including changes in crop management.

In the Maritime zone of Europe, genetically modified (GM) crops are not as yet commercially cultivated on a large scale. Iin this report the Maritime zone is according to the definition by EPPO standard PP1/241(1) (www.eppo.int), is the zone north of the line from the coastal zone of south-west France, through Lyon (France), to the south border of Switzerland and Austria, west of the border between Austria and Hungary, west of the border between Czech Republic and Slovakia, and west of the river Oder (between Poland and Germany). This zone also includes Ireland, Sweden and the United Kingdom. A re-occurring topic in the discussion on the introduction of GM crops is the nature and extent of indirect changes of cultivation of GM varieties.

The aim of this report is to provide insight in the possible changes in crop cultivation practices after the possible introduction of GM varieties of maize, sugar beet and potato in the Maritime zone of Europe. Alternatives to the use of current available GM varieties, which may currently be developing into new strategies, are not taken into account. This report is not intended to formulate future information requirements used by the COGEM for consultancy.

Outside Europe, GM varieties of soybean, maize, cotton and sugar beet are cultivated and several changes have occurred in the agro systems in the regions of introduction. These changes have been reviewed with respect to their relevance to the Maritime zone. In this report, we reviewed only changes in cultivation practice. Direct effects on the environment and socio-economic parameters are not part of this review.

We evaluated the changes that occurred in the United States of America (USA) because 43% of all GM crops are grown in that country and changes have been relatively well documented. Furthermore, the adoption rate of the GM varieties in the USA is large, ranging from 85% for Maize to 93% for Cotton. GM crop varieties cultivated on a commercial scale are resistant to herbicides, insects, (and viruses), or a combination of these characteristics. Farmers have adopted these GM varieties for three reasons: cost savings, better (weed and/or pest) management, and simplicity of use. The use of GM varieties has altered the following farmers' agronomic practices: tillage, herbicide use and weed control, insecticide use, and resistance management. General trends were observed:

- Farmers who use GM varieties are more likely to adopt No tillage systems and vice versa: in No tillage systems farmers are more likely to adopt HR varieties.
- GM crops reduced overall pesticide use (that is the total of insecticides and herbicides) in the USA by 1.2%, 2.3% and 2.3% per year, in the first three years of commercial introduction (1996-1998) but increased pesticide use by 20% in 2007 and by 27% in 2008, compared to the amount of pesticide likely to have been applied in the absence of HR and Bt seeds. This increase can be attributed to the increased use of herbicides completely. Since the introduction of Bt crops the amount of insecticides used decreased.
- Herbicide resistant weed species have developed more rapidly under GR (glyphosate-resistant) crops than they would have done under conventional varieties in which several herbicides with different modes of action would have been used. Some of these species have multiple resistances to two or more modes of action due to the previous development of resistance against other modes of action in conventional systems.
- Development of resistant insects has been largely prevented with the creation of conventional crop refuges amidst Bt fields and the use of crops with multiple Bt toxins. However, the first reports exist on pest resistance, for instance in WCR (Western Corn Rootworm) in Iowa, which could partly be related to continuous maize cultivation and insufficient refuge planting.

The relevance of these practices was studied for the Maritime zone of Europe with respect to possible introduction of GM crops in future. The following questions have been answered: what are the current practices, which transgenic traits are likely to be introduced in maize, sugar beet and potato in the zone and how would this alter the cultivation of these crops?

In the Maritime zone farmers are likely to choose methods that they perceive as easier, simpler and cheaper as well.

The introduction of HR maize will most likely reduce the application of some traditional herbicides that are rather persistent. The risk of the development of glyphosate resistant weeds will increase when HR maize is grown in a continuous maize rotation without proper resistance management.

The HR maize varieties could make weed control in maize ‘easier and simpler’ in the Maritime zone, making a large adoption of these varieties in the Maritime zone likely. However, the costs or cost savings are equally important to farmers. The adoption of HR maize also depends on the costs of the HR and conventional seeds and the price of glyphosate and alternative herbicides.

Other influential aspects may be the legal obligation to grow a green manure crop following a maize crop and the possibility to apply conservation tillage with HR maize. The use of HR maize varieties would increase the possibilities of farmers to grow a green manure crop in between two maize crops, which currently delays the sowing date of conventional maize and reducing the potential yield. With HR maize it could be possible to apply conservation tillage in which maize can be grown after grassland. Maize can be directly seeded in small strips in the grassland in which the soil is prepared for sowing, leaving the soil surface undisturbed between the rows. The grassland does not have to be ploughed deep into the soil or killed chemically before the maize is sown, but can be killed after maize emergence. This would leave grass residues in the top layer of the soil and would reduce soil structural damage during harvest in autumn. In areas that suffer from soil erosion, the introduction of HR maize may make reduced tillage feasible, reducing the risk of soil erosion.

Currently the available IR maize varieties are resistant against the WCR (Western Corn Rootworm) and ECB (European Corn Borer). The ECB occurs in warmer parts of Europe, and is already present in the southern part of the Maritime zone. Thus, some Bt maize (with the MON810 event against ECB) is already grown in the Czech Republic. The WCR has been found, but is not a large problem yet, although it could enter the southern part of the Maritime Zone with climate warming. If population sizes increase, the stacked GM varieties, containing resistance against both types of insects (lepidopterans and coleopterans) as well as herbicides would gain interest. A significant avoidance of insecticide use could therefore be hypothesized for the introduction of Bt maize.

The introduction of maize varieties containing the transgenic event conferring drought tolerance is not expected to change cultivation aspects other than the reduction of the need for irrigation and an expansion of maize cultivation to dryer areas.

Weed control in sugar beet in the Maritime zone is not currently an easy task for growers. Therefore, interest in HR sugar beet may be expected in this area of Europe. It could make a good option for using herbicides to control weed beet, the most challenging weed in sugar beet. However, for weed beet, there is a specific risk of obtaining glyphosate resistance through hybridization with HR sugar beet, both in seed production areas mainly located outside of the Maritime Zone and in the beet production areas within the Maritime zone. Therefore, strict bolter control is necessary in the beet production areas to suppress development of transgenic HR weed beets. The number of herbicide applications during cultivation is likely to be reduced from 3-5 times to 1-3 times, when HR sugar beets are grown in rotations in which several herbicides with different modes of actions are used.

Sugar beet is often grown in rotation with cereals in which perennial weed species can be problematic. Weed control in those crops can be easier when these species are controlled in the preceding sugar beet crop at the right time. HR sugar beet could provide the possibility to control these species with herbicides during sugar beet growth.

None of the traits introduced in current or known future GM sugar beet varieties aims at insect or disease resistance. Currently there are no large scale problems with pests or diseases in sugar beet in the Maritime zone. In that respect the introduction of sugar beet GM varieties is not likely to alter any insecticide or fungicide use.

The most likely traits to be introduced into commercial potato cultivation in the Maritime zone are an output trait, namely a change in starch composition from a mixture of amylose and amylopectin to an amylose free potato, and resistance to potato late blight. The amylose depleted trait is an output trait with little likelihood of changes in cultivation practices.

A successful introduction of GM late blight resistant potato will potentially bring down fungicide applications up to 75%. However, the reduced application of fungicides may be accompanied by the development of secondary pests, and reduction of fungicides may be lower in reality. Because the same elite varieties as presently cultivated form the basis of the cisgenic late blight resistant lines, no other crop cultivation changes are expected.

Samenvatting

Dit rapport is het resultaat van een project waarin getracht werd de volgende onderzoeksvraag van de COGEM te beantwoorden: welke teeltveranderingen kunnen in de maritieme zone van Europa verwacht worden na een mogelijke introductie van genetisch gemodificeerde (GG) maïs, aardappel en suikerbiet? Aanleiding voor deze onderzoeksvraag vormden de EU Richtlijn 2001/18/EC (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:106:0001:0038:EN:PDF) en de interpretatie daarvan door de EFSA (European Food Safety Authority) (http://www.efsa.europa.eu/en/scdocs/doc/1879.pdf). Beiden eisen een volledige evaluatie van mogelijke veranderingen als gevolg van de introductie van GG gewassen, inclusief teeltveranderingen.

In de Maritieme zone van Europa worden GG gewassen momenteel niet op grote schaal geteeld. De Maritieme zone (Maritime zone of Europe) waar in dit rapport naar verwezen wordt is de zone zoals deze door EPPO standaard PP1/241(1) (www.eppo.int) is beschreven: de zone ten noorden van de lijn vanaf de kust van zuidwest Frankrijk, vanaf Lyon (Frankrijk) tot aan de zuidelijke grens van Zwitserland en Oostenrijk, en ten westen van de rivier de Oder (tussen Polen en Duitsland). Deze zone omvat tevens Ierland, Zweden en Groot Brittannië.

Het doel van dit rapport is het geven van inzicht in de mogelijke veranderingen in de teelt van de gewassen na de mogelijke introductie van GG variëteiten van maïs, suikerbiet en aardappelen in de boven genoemde Maritieme zone. Mogelijke alternatieven voor het gebruik van GG gewassen die momenteel in ontwikkeling zijn worden niet meegenomen in deze studie.

Buiten Europa worden al GG variëteiten van soja, maïs, katoen en suikerbiet verbouwd en zijn verscheidene veranderingen in de agrosystemen waargenomen. Deze veranderingen zijn in dit rapport onderzocht op eventuele indirecte effecten en hun relevantie voor de Maritieme zone van Europa. In dit rapport zijn alleen de teeltveranderingen bestudeerd. Directe effecten op het milieu en socio-economische veranderingen maken geen onderdeel uit van deze studie.

We evalueerden de veranderingen die in de Verenigde Staten (VS) hebben plaatsgevonden na de introductie van GG gewassen omdat 43% van alle GG gewassen ter wereld in dat land verbouwd worden. Bovendien zijn de veranderingen in dat land relatief gezien goed gedocumenteerd en zijn de cijfers betrouwbaar. Daarnaast past het overgrote deel van de ondernemers in dat land GG gewassen toe, van 85% voor maïs tot 93% voor katoen.
De GG gewassen die daar commercieel worden geteeld zijn resistent tegen herbiciden, insecten (en virussen), of bevatten een combinatie van deze eigenschappen. Telers passen deze GG variëteiten vanwege een drietal redenen op grote schaal toe: gereduceerde kosten, betere beheersing van onkruiden en/of plagen, en de eenvoud in gebruik. De teelt van de gewassen is op de volgende punten veranderd: grondbewerking, herbicide gebruik en onkruidbeheersing, insecticiden gebruik en resistentie management. Er werden enkele algemene trends waargenomen:

- Ondernemers die GG gewassen telen, zijn eerder geneigd No till of minimale grondbewerkingssystemen toe te passen en vice versa.
- Het totale pesticiden (insecticiden en herbiciden) gebruik nam in de VS gedurende de eerste drie jaar (1996-1998) na commerciële introductie van GG gewassen af met 1.2%, 2.3% en 2.3% per jaar, maar nam daarna toe tot met 20% in 2007 en 27% in 2008, in vergelijking met de hoeveelheid die naar alle waarschijnlijk in afwezigheid van herbicide en insecticide resistente gewassen zou zijn toegepast. Deze toename is in zijn geheel toe te schrijven aan een toegenomen herbicidengebruik, voornamelijk glyfosaat. Gebruik van andere herbiciden is afgenomen. Sinds de introductie van Bt gewassen is de hoeveelheid insecticiden afgenomen (Benbrook, 2009).
- Herbicide resistente onkruiden hebben zich in herbicide resistente gewassen sneller ontwikkeld dan ze zich zouden hebben ontwikkeld onder conventionele gewassen, waarin meerdere herbiciden met een verschillend werkingsmechanisme worden gebruikt. Doordat resistente onkruiden zich in het verleden ook al in gangbare teelten hadden ontwikkeld, bestaan er nu meerdere onkruidsoorten die resistent zijn tegen herbiciden met een verschillend werkingsmechanisme.

- De ontwikkeling van resistente insecten is voor een groot deel voorkomen door het gebruik van zogenaamde vluchtgewassen: conventionele gewassen die geteeld worden tussen Bt gewassen en door het gebruik van gewassen met meerdere Bt toxines. Echter, de eerste meldingen van resistentie in de maïswortelkever werden recent gedaan in bijvoorbeeld Iowa en zijn zeer waarschijnlijk toe te schrijven aan de continue maïsteelt en onvoldoende teelt van vluchtgewassen.

De relevantie van deze veranderingen en trends voor de Maritieme zone werd onderzocht. Daaruit bleek dat vereenvoudig en kostenbesparing voor ondernemers in de Maritieme zone eveneens doorslaggevende factoren kunnen zijn bij de keuze voor GG gewassen. De herbicide resistente maïs kan onkruidbeheersing makkelijker en eenvoudiger maken in de zone, waarmee adoptie van deze variëteiten op grote schaal in de zone waarschijnlijk wordt. Echter, de kosten of eventuele kostenbesparing zijn ook erg belangrijk voor telers. De mate van adoptie zal dus ook afhangen van de prijs waarmee deze en conventionele gewassen in de markt zullen worden gezet als ook van de prijs van glyfosaat en alternatieve herbiciden.

De introductie van HR maïs zal naar alle waarschijnlijkheid het gebruik van enkele traditionele herbiciden, waaronder enkele behoorlijk persistente, verminderen. De kans op een snellere ontwikkeling van glyfosaat resistente onkruiden zal naar verwachting groter worden wanneer de HR maïs net als de gangbare maïs nu in een continu teelt geteeld zal worden en er onvoldoende aan resistentie management gedaan zou worden.

Andere aspecten die van invloed kunnen zijn, zijn de verplichting om een groenbemester (vanggewas) na de maïs te telen en de mogelijkheid om gereduceerde grondbewerking toe te passen in combinatie met herbicide resistente maïs. Door toepassing van de HR maïs kan een teler gemakkelijker een groenbemester telen tussen twee maïs-gewassen in. Momenteel wordt de groenbemester in het voorjaar vaak door middel van een glyfosaatbehandeling gedood en vervolgens ondergeploegd. Soms wordt de groenbemester ondergeploegd zonder dat deze vooraf wordt doodgespoten. De groenbemester kan gaan hergroeien in het maïsgewas, en kan daarmee een risico op opbrengst-vermindering met zich meebrengen. Een eventueel gebruik van HR maïs zou de bestrijding van hergroei kunnen vergemakkelijken omdat in HR maïs de groenbemester nog zonder schade na de zaai van maïs met herbiciden bestreden zou kunnen worden. Indien de groenbemester in het voorjaar als veevoer geoogst zou worden, dan zou het met HR maïs mogelijk zijn om de maïs direct na deze oogst te zaaien in strips en de groenbemesterstoppel pas na opkomst van de maïs te doden met herbiciden. In een regulier maïs gewas moet de groenbemester voorafgaand aan de zaai van maïs bespoten worden en ondergeploegd worden. Dit kost tijd, omdat het voor een goed effect van de glyfosaatbespuiting nodig is dat de stoppel eerst hergroei vertoont. Als gevolg hiervan is het nodig het moment van zaaien van maïs uit te stellen wat ten koste gaat van de maïsopbrengst. De zaai uitstellen zou bij de HR maïs niet nodig zijn. De toepassing van niet kerende grondbewerking zou ook vergemakkelijken met HR maïs, wanneer deze in rotatie met grasland wordt geteeld. De HR maïs kan direct in het grasland worden gezaaid, omdat het gras niet hoeft te worden ondergeploegd of gedood met herbiciden voor de zaai van de maïs. Een glyfosaatbehandeling na opkomst van de HR maïs kan het grasland doden waardoor grasresiduen in de toplaag overblijven. Deze verminderen op hun beurt weer het risico op bodemstructuur schade gedurende de oogst.

Momenteel zijn de beschikbare IR maïs gewassen resistent tegen *Diabrotica* spp. (maïswortelkever) en *Ostrinia nubilalis* (maïsstengelboorder). De maïsstengelboorder komt voor in warmere zones van Europa, waaronder ook in het zuiden van de Maritieme zone. In Tsjechië vindt dan ook enige teelt plaats van IR Bt maïs (met het transgene 'event' MON810 tegen de maïsstengelboorder). De maïswortelkever is aangetroffen, maar vormt op dit moment nog geen groot probleem in de Maritieme zone. Wanneer echter deze populatie(s) toenemen in de zone, zullen de variëteiten met zowel resistentie tegen herbiciden als ook tegen insecten interessant worden voor de zone. Daarmee kan aangenomen worden dat de hoeveelheid toegepaste insecticide zal afnemen met de introductie van Bt maïs. De introductie van droogteresistente maïs zal naar verwachting geen andere teeltwijzigingen met zich meebrengen dan een reductie van de hoeveelheid benodigde irrigatie en een mogelijke uitbreiding van het areaal naar drogere gronden.

Op dit moment is de onkruidbestrijding in suikerbiet in de Maritieme zone niet eenvoudig. Er is veel kennis nodig om de juiste middelen op de verschillende percelen toe te passen. Door het telen van GG suikerbiet zou het aantal benodigde herbicidenbespuitingen waarschijnlijk van drie tot vijf naar een tot drie teruggebracht kunnen worden. Ook zou voor de bestrijding van aardappelopslag geen extra bespuiting nodig zijn omdat deze opslag tegelijk met de andere onkruiden bestreden kan worden in het maïsgewas. De onkruidbiet is een belangrijk probleem onkruid in de huidige teelt. Door het gebruik van een herbicide resistent suikerbiet, zou ook deze onkruidsoort goed tijdens de teelt bestreden kunnen worden. De huidige, veelal handmatige, bestrijding kan dan achterwege blijven. Met de onkruidbiet is er echter een specifiek risico op het ontwikkelen van transgene herbicideresistentie via hybridisatie met de HR suikerbiet, zowel in de zaadproductiegebieden die voornamelijk buiten de Maritieme zone liggen, als de bietenproductiegebieden in de Maritieme zone. Dat maakt strikte schieterbestrijding in de bietenproductiegebieden noodzakelijk om ontwikkeling van transgene HR onkruidbieten tegen te gaan. Suikerbiet wordt vaak geteeld in rotatie met granen waarin meerjarige onkruiden problematisch kunnen zijn. Deze meerjarige onkruiden zouden door bespuitingen gedurende de teelt van HR suikerbiet op het juiste moment bestreden kunnen worden waardoor ze minder tot geen probleem in de granen opleveren. Geen van de eigenschappen die in de huidige of ons bekende GG suikerbietvarianten in de pijplijn voor commerciële teelt zijn betreft resistentie tegen ziekten of plagen. Bovendien zijn er momenteel geen grote problemen op grote schaal met ziekten en plagen in suikerbiet in de zone. In dat opzicht zal de introductie van GG suikerbiet naar verwachting geen teeltwijzigingen met zich meebrengen.

In aardappel zijn de meest waarschijnlijke eigenschappen die ingebouwd zullen worden een zogenaamde 'output trait', namelijk een verandering van de zetmeelsamenstelling (van een mengsel van amylose en amylopectine naar een amylose vrije aardappel) en een ziekteresistentie, tegen *Phytophthora infestans*. De amylopectine eigenschap zal de teelt van de aardappel naar alle verwachting niet wijzigen. Veldproeven hebben tot nog toe geen teelt-wijzigingen laten zien. De introductie van een aardappel die resistent is tegen *P. infestans* kan het gebruik van fungiciden potentieel met 75% reduceren. Echter, de gereduceerde toediening van fungiciden kan een toename van het aantal secundaire ziekten met zich meebrengen, waardoor de werkelijke afname van fungiciden wellicht lager uitvalt. Omdat de verwachte aardappelrassen met de *P. infestans* resistentie dezelfde zijn als de rassen die momenteel op grote schaal verbouwd worden, worden er geen andere teeltwijzigingen waarschijnlijk geacht na introductie.

Abbreviations and Definitions

GE	Genetically engineered
GM	Genetically modified
GR	Glyphosate resistant
HT	Herbicide tolerant
HR	Herbicide resistant
IR	Insect resistant
VR	Virus resistant
Bt	*Bacillus thuringiensis*
ECB	European Corn Borer
WCR	Western Corn Rootworm
RR	Roundup Ready

Maritime Zone	The zone north of the line from the coastal zone of south-west France, through Lyon (France), to the south border of Switzerland and Austria, west of the border between Austria and Hungary, west of the border between Czech Republic and Slovakia, and west of the river Oder (between Poland and Germany). This zone also includes Ireland, Sweden and the United Kingdom (EPPO standard PP1/241(1)).
Herbicide Resistance	The inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis (WSSA, 1998).
Herbicide Tolerance	The inherent ability of a species to survive and reproduce after herbicide treatment. This implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant (WSSA, 1998).
Stacked Cultivars	Cultivars with multiple GM characteristics, irrespective of methodology.

1. Introduction

1.1 Background and aim

In the Maritime zone of Europe, genetically modified (GM) crops are not yet commercially cultivated on a large scale. The Maritime zone in this report is the zone defined by EPPO standard PP1/241(1) (www.eppo.int), i.e. the zone north of the line from the coastal zone of south-west France, through Lyon (France), to the south border of Switzerland and Austria, west of the border between Austria and Hungary, west of the border between the Czech Republic and Slovakia, and west of the river Oder (between Poland and Germany). This zone also includes Ireland, Sweden and the United Kingdom (Figure 1).

Figure 1. the Maritime zone of Europe as defined by EPPO standard PP1/241(1).

There is a lot of discussion concerning the possible introduction of GM varieties in Europe. A re-occurring topic is the nature and extent of indirect changes in cultivation practices as a result of introduction of GM varieties. Directive 2001/18/EC of the European parliament and council (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri =OJ:L:2001:106:0001:0038:EN:PDF) on the deliberate release into the environment of genetically modified organisms refers to indirect effects as 'effects on human health or the environment occurring through a causal chain of events, through mechanisms such as interactions with other organisms, transfer of genetic material, or changes in use or management'. The directive does not elucidate the type of changes in use or management. The European Food Safety Authority (EFSA) document (http://www.efsa.europa.eu/en/scdocs/doc/1879.pdf) provides guidance for the environmental risk assessment (ERA) of GM plants submitted under this directive. The EFSA document states that 'GM plants shall be fully risk assessed for the potential impacts of their cultivation, management and harvesting techniques' during the ERA. The document provides some examples of possible changes, but does not give a complete overview of the possible changes that should be assessed. These descriptions in the EU directive 2001/18/EC and the EFSA guidance document induced the COGEM to formulate the following research question: which cultivation changes for specific GM crops can be expected in Europe, based on currently available data and information from areas in which these crops have been grown for several years.

The aim of this report is to provide insight into the possible changes in crop cultivation practices after the introduction of GM varieties of maize, sugar beet and potato in the Maritime zone of Europe. Alternatives, currently being developed into new strategies, to the use of GM crops are not taken into account. This report is not intended to formulate future information requirements used by the COGEM for consultancy.

The introduction of GM varieties can impose several changes on crop cultivation. Some of these changes are relatively easy to foresee. The shift in crop protection products that are used in the case of herbicide-resistant (HR) crops for instance. Others, however, may not be as obvious. Any occurrence of changes in crop rotation or fertilization is much harder to predict as possible relationships with for instance the HR trait are more complex.

1.2 Methodology

Outside Europe, GM crop varieties have been cultivated for more than fifteen years now. GM varieties of soybean, maize and cotton are grown on a very large scale and several changes in crop cultivation practices in the regions of introduction have been documented. An analysis of these changes can provide us with valuable insight into the type of changes that can be expected.

As a starting point we used recent reports on the sustainability of the GM crops soybean, maize, cotton (Franke *et al.*, 2011), sugar beet and potato and on observed unexpected effects of GM crop cultivation (Van den Brink *et al.,* 2010). We used the effects found there with relevance for crop cultivation and extended these with recent publications, unpublished observations and consulted experts from the United States, amongst who: Dr. Eric Gallandt (University of Maine, Prof Dr. Dave Mortensen (Penn State University) and Dr. Mike Owen (Iowa State University).

In Chapter 2 the observed changes in the cultivation of soybean, maize, cotton, sugar beet and potato after introduction of GM varieties are described for regions outside of the Maritime Europe zone, particularly the USA. The common cultivation practices before the introduction of GM varieties were used as a reference. Three of these crops are commonly also grown in Europe: maize, sugar beet and potato. Observed changes in the cultivation of these crops in the USA will be used to generate an overview of the most likely changes in these crops in Europe. However, due to differences in scale and rotations, results cannot be directly used to predict the changes for crops and regions of interest in Europe. Soybean and cotton are not widely grown in Europe. There is, however, a lot of data available on cultivation changes after the introduction of GM varieties of these crops in the USA. Therefore, the observed changes in soybean and cotton will be used to provide a good overview of general trends in crop cultivation change after introduction of GM varieties.

These following changes are reviewed (Table 1) and their relevance to the Maritime zone is discussed. In this report, we will only review changes in cultivation practices. Direct effects on the environment and socio-economic parameters are not part of this review.

Table 1. Overview of possible cultivation changes after introduction of GM varieties reviewed in this report.

Crop cultivation changes possible after introduction of GM varieties	Reviewed in this report yes/no
Soil tillage	Y
Herbicide use	Y
Weed control	Y
Insecticide use	Y
Weed Resistance management	Y
Insect Resistance management	Y
Availability of non-GM seed	Y
Rotation	Y
Fertilization	Y
Irrigation	Y
Disease resistance management	Y
Disease control	Y
Environmental effects	N
Socio-economic effects	N

Based on the current crop cultivation practices of the crops of interest in Maritime Europe, maize, sugar beet and potato, the crop cultivation changes after introduction of GM varieties relevant to the conditions in the Maritime zone are identified. The Maritime zone includes both coastal zones as areas with more continental characteristics. Therefore, in this review we used the Netherlands as a reference and upgraded our findings to the whole Maritime zone when possible. Chapters 3, 4 and 5 describe 1) the current cultivation practices in maize, sugar beet and potato in the Maritime zone specifically, 2) an overview of the specific traits being incorporated in the GM varieties that are the most likely introduced in the foreseeable future, and 3) an overview of the cultivation changes that are likely to occur when these GM crops are introduced in the Maritime zone.

In Chapter 6, possible trends related to GM crop introduction are discussed in relation to general developments in agriculture in the Maritime zone and conclusions are given.

2. Observed crop cultivation changes after GM introduction: Maize, Soybean Cotton, Sugar beet and Potato

This chapter provides an overview of the observed crop cultivation changes after introduction of a GM crop. In this review we focused on the changes that took place in the USA, because 43% of all GM crops are grown in that country (Table 2) and changes have been relatively well documented. Furthermore, the adoption percentage of the GM varieties in the USA is very large, ranging from 85% for Maize to 93% for Cotton (Table 3).

Table 2. Distribution of GM crop acreage in the world in 2011 (James, 2011).

Country	Area (Mha)	% of total
USA	69.0	43
Brazil	30.3	19
Argentina	23.7	15
India	10.6	7
Canada	10.4	7
China	3.9	2
Paraguay	2.8	2
Pakistan	2.6	2

Table 3. Percentage of GM varieties planted in the USA in 2011 per crop (Brookes & Barfoot, 2012).

Crop	Percentage GM varieties of all varieties planted in 2011
Maize	86
Soybean	93
Cotton	93
Sugar beet	95

2.1 Available GM crops

The first activities in the development of genetically modified or engineered (GM or GE) crops focused on traits that affect weed and/or pest control. The available GM crops provide pest control in one or more of three forms (National Research Council, 2010): Herbicide resistance (HR), Insect resistance (IR) and Virus resistance (VR).

In this report we use the following definitions for herbicide resistance and herbicide tolerance as defined by the WSSA (Weed Science Society of America) (WSSA, 1998).

Herbicide resistance: the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis. Herbicide tolerance: the inherent ability of a species to survive and reproduce after herbicide treatment. This implies that there was no selection or genetic modification to make the plant tolerant; it is naturally tolerant. Several different definitions of these terms are used in literature and in previous reports of some of the authors other terminologies have been used as well. In this report, however, we prefer to use a scientifically refereed definition which has been approved by one of the leading societies in the field of weed science. In the USA, HR crops are available with resistance to glufosinate and glyphosate. Most HR crops grown in the USA are resistant to glyphosate only (National Research Council, 2010). HR crops are engineered to survive direct post-emergence application of one or more herbicides. IR crops grown in the USA have genetic material from the soil-dwelling bacterium *Bacillus thuringiensis* (Bt) incorporated into their genome that provides protection against particular insects. VR crops are commercially available but not grown on a large scale and provide protection against viruses.

HR and IR crops account for the largest number of acres planted with GM crops in the USA. HR varieties of soybean, maize, cotton, canola and sugar beet and IR varieties of maize and cotton were commercially grown in 2011 in the USA (James, 2011). Herbicide resistance and Insect resistance are often combined in the same variety; GM maize and cotton may also express more than one type of a Bt trait. Seeds with multiple GM characteristics are referred to as 'stacked cultivars' (National Research Council, 2010). Table 4 gives an overview of the currently approved HR crops.

Table 4. Glyphosate resistant crops that have been approved for sale in the USA. After: Duke & Powles 2009.

Crop	Year of approval
Soybean	1996
Canola	1996
Cotton	1997
Maize	1998
Sugar beet*	1999
Alfalfa**	2005

* *Removed from market after first introduction, but reintroduced in 2008.*
** *Returned to regulated status in 2007 by court order, commercial planting resumed in 2011 (James 2011).*

Maize

In 2011, 86% of all maize planted in the USA was some kind of GM maize (Table 3). The first GM maize variety that came on the market in 1996 was an IR variety (against European Corn Borer, ECB, *Ostrinia nubilalis*). The first HR variety was introduced in 1997 (glyphosate resistant), followed by a second HR variety in 1998 (glufosinate resistance). Another IR variety with a different Bt toxin was introduced (against Western Corn Rootworm, WCR, *Diabrotica virgifera*) in 2003.

The adoption of HR maize was rather low initially (with only 8% in 2001) in all USA regions (Figure 2). Instead of spraying glyphosate after maize emergence farmers rather relied on traditional strategies for pre-emergence herbicide control, which in combination with the higher prices of the HR maize seed made the use of HR maize unprofitable. Another important aspect in the slow adoption of HR maize was the lack of market access for HR maize to the European Union (National Research Council, 2010).

Due to the variable insect pressure, the adoption of the IR maize varieties was also relatively low (19% in 2001, Figure 2). In regions with high insect densities, more than 30% of the maize acreages were planted with IR maize, while in regions with lower densities only 6% of the maize acreages were planted with IR maize (National Research Council, 2010).

In 2002, stacked gene hybrids containing multiple resistance traits were introduced. This resulted in a large increase in the adoption of GM maize.

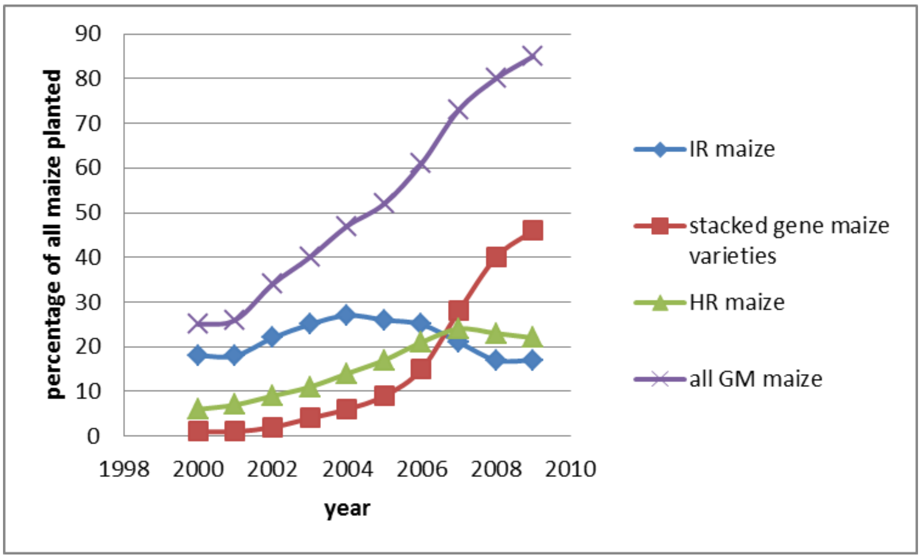

Figure 2. *The amount of GM maize grown in the USA, as a percentage of total maize planted. Source: National Research Council 2010.*

Soybean

Soybean resistant to the herbicide glyphosate was first introduced in the USA in 1996. Just four years later, the GM cultivars accounted for 54 % of all soybean area planted. A major factor in the rapid adoption was the superior control of a broad spectrum of weeds with a single timely application of glyphosate, including many problematic weeds (Mulugeta & Boerboom, 2000). Other important factors were the perceived simplicity and the relative safety (only one single application of a single active ingredient compared to multiple applications of tank-mixed herbicides), lack of crop injury, and the relatively low costs of herbicides. The adoption continued (Figure 3) and nowadays 93% of the area is planted with HR soybean (Table 3).

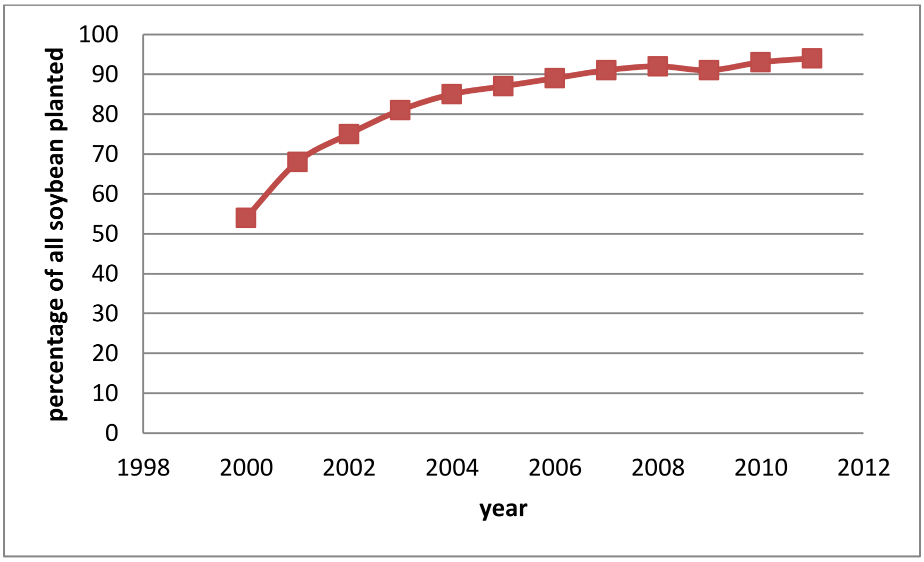

Figure 3. *The amount of GM soybean grown in the USA, as a percentage of total soybean planted. Only HR soybean is available. Source: National Research Council, 2010.*

Cotton

The first GM cotton cultivars contained resistance against insects and were commercialized in 1996. One year later glyphosate resistant (GR) cotton was introduced. Both types of GM cotton were popular among farmers, mainly because weed management traditionally has been more challenging in cotton than in many other field crops (Jost *et al.,* 2008). The Bt-GR variety was introduced in 1997. In 2001, GM cotton was grown on 69% of the total cotton acreage: 32% GR only, 13% IR only and 24% stacked varieties (Figure 4). A new variety of GR cotton introduced in 2006 provided growers with a wider window for glyphosate application and the possibility of using higher glyphosate dosages (Mills *et al.,* 2008). At around the same time IR cotton with two Bt endotoxins was introduced, which provided much more protection against a range of pests. These introductions contributed to the increase of GM cotton to 93% in 2010: 30% GR only, 3% IR only and 67% stacked (James, 2010), and to a total of 93% in 2011 (Table 3).

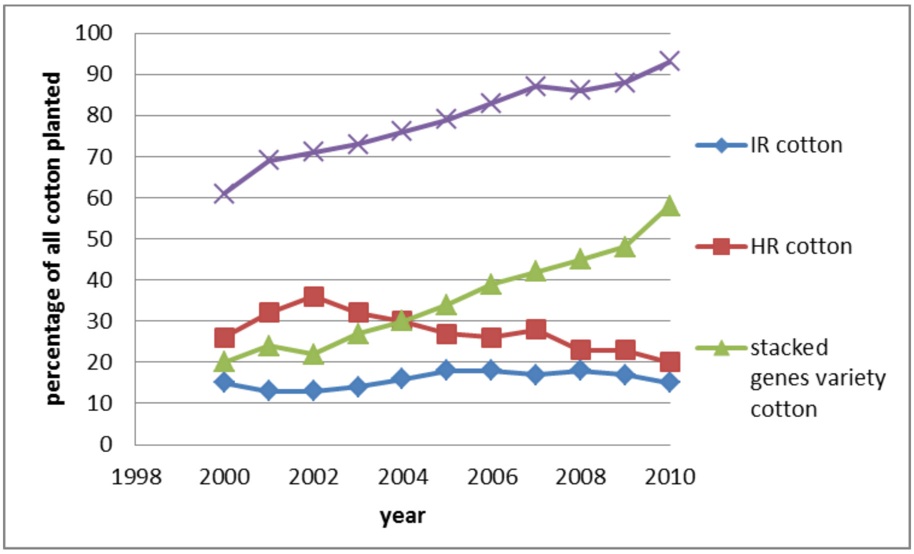

Figure 4. *The amount of GM cotton grown in the USA, as a percentage of total cotton planted. Source: National Research Council 2010.*

Sugar beet

HR sugar beet was approved for commercial use in 1998, but concerns about marketplace acceptance precluded the commercial release of the transgenic cultivars (Duke, 2005). Herbicide resistant GM sugar beet varieties were introduced into the market in 2007 in the USA. It was rapidly adopted by farmers and in 2009 already accounted for nearly 95% of the acreage of all sugar beets produced in the USA (James, 2010), making it the fastest adopted GM crop to date. It was grown on 475,000 ha in the USA in 2011 (James 2011). The HR sugar beet is resistant to glyphosate (Graef *et al.,* 2010). The only other country in which HR sugar beet is commercially grown is Canada with an approximate 20,000 ha acreage.

Potato

A Bt potato resistant against herbivorous activities of certain *Coleoptera* species including the Colorado potato beetle was commercialized in 1995. Three years later, the technology developer, Monsanto, introduced a stacked variety that combined the Bt trait with virus resistance. Although the first reports noted a large potential for reduced pesticide use, Monsanto discontinued the sale of GM potatoes in 2001 (National Research Council, 2010). The cultivars failed to capture more than 2-3 per cent of the market for two reasons. Firstly, a new insecticide that controlled the Colorado potato beetle and other pests were introduced to the market at around the same time as the GM potatoes; most farmers chose the insecticide over the GM trait (Nesbitt, 2005). Secondly, potato processors experienced a public-pressure campaign against the use of GM potatoes (Kaniewski & Thomas, 2004).

2.2 Agricultural changes since introduction

Since their introduction the use of GM crops in the USA has grown rapidly and altered farmers' agronomic practices, such as tillage, herbicide use, mechanical weed control, insecticide application and resistance management. Each of the changes is described per cultivation practice in the following sections.

The use of GM varieties has altered farmers' agronomic practices. Tillage, herbicide use, mechanical weed control, insecticide application and resistance management practices changed.

Tillage

Tillage is used by farmers to prepare the soil before planting. In conventional tillage, all postharvest residue is ploughed into the soil to prepare a clean seed bed for planting and to reduce weed growth. Conservation tillage has been stimulated in the USA since the 1960s. In conservation tillage, at least 30 per cent of the soil surface is left with crop residue after planting. Several innovations in cultivations and seeders enabled farmers even to adopt no-till. In no-till systems, the soil and surface residue of the previous crop are left undisturbed as the next crop is seeded directly into the soil without tillage. Due to the Food Security Act of 1985, conservation tillage accelerated in the 1990s. The introduction of HR soybean and cotton supported the trend because the use of glyphosate allowed easier weed control after crop emergence during a larger time window, without the need of tillage. During the last ten years the use of conservation tillage has continued to increase, with the exception maize, in which it has remained constant (Figure 5).

From the perspective of farmer decision making, the availability of HR technology may affect the adoption of conservation tillage, and the use of conservation tillage may affect the adoption of HR crops. Several studies were undertaken to understand how closely the two decisions are linked. Earlier studies (Fernandez-Cornejo *et al.* 2003) amongst soybean growers indicated that farmers using no-tillage were more likely to adopt HR crops than farmers using conventional tillage, but farmers using HR crops were not more likely to adopt conservational tillage. However, more recent studies including soybean farmers (Mensah, 2007), found a two-way causal relationship on the basis of more recent data. They found that farmers who adopted no-till were more likely to adopt HR soybeans and those farmers who adopted HR crops were more likely to adopt no-till practices.

The results for cotton point to the same two-way causal relationship as for soybean. Roberts *et al.* (2006) found that cotton growers in Tennessee in the period 1992 to 2004 were more likely to adopt HR crops when they already used no till, and were more likely to adopt no till systems when they were using HR crops. Similarly, Kalaitzandonakes and Suntornpithug (2003) studied the adoption of HR and stacked cotton varieties and conservation tillage practices on the basis of farm-level data. They concluded that conservation tillage practices both encouraged the adoption of HR and stacked cotton varieties and were encouraged by their adoption. Frisvold *et al.* (2009) also found strong complementary relationships between conservation tillage and the adoption of HR and rejected the hypothesis that the adoption of one is independent of the other.

Thus, most empirical evidence points to a two-way causal relationship between the adoption of conservation tillage and the adoption of HR crops. It is not clear which factor has a greater influence on the other (National Research Council, 2010).

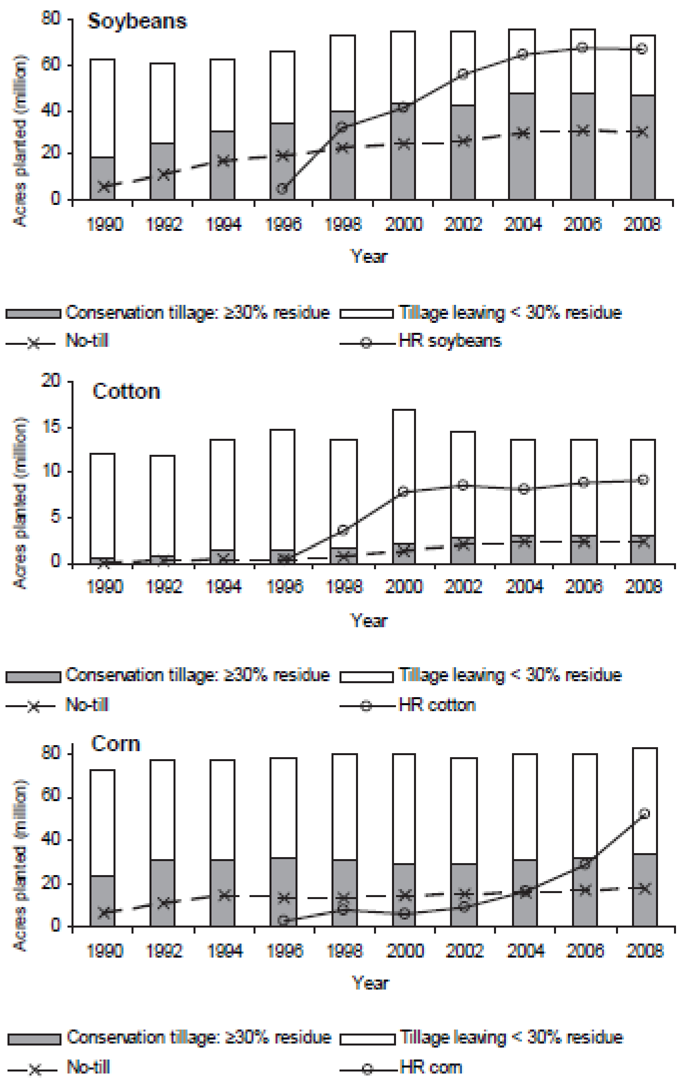

Figure 5. *Type of tillage used and the acres planted with HR crops (source of graph: National Research Council (2010), original data not available). 10 acres ~ 4, 05 ha.*

In No tillage systems the adoption of GM varieties is more likely, and vice versa: in systems with a high percentage of GM varieties the adoption of No tillage is more likely.

No tillage is a form of conservation agriculture, which was mainly introduced to prevent soil erosion.

Pesticide use

GM crops reduced overall pesticide use (that is the total of insecticides and herbicides) in the USA in the first three years of commercial introduction (1996-1998) by 1.2%, 2.3% and 2.3% per year, but increased pesticide use by 20% in 2007 and by 27% in 2008, compared to the amount of pesticide likely to have been applied in the absence of HR and Bt seeds. This increase can completely be attributed to the increased use of herbicides, particularly glyphosate, partly at the cost of other types of herbicide. Since the introduction of Bt crops the amount of insecticides used decreased (Benbrook, 2009).

Herbicide use and weed control

The introduction of herbicide resistant crops changed weed management tactics in soybean, cotton, maize and sugar beet dramatically. Most of the planted HR crops are resistant to the herbicide glyphosate. Farmers have adopted herbicide resistant (HR) crops for three main reasons (Duke & Powles, 2009):

- Cost savings
- Better weed management
- Simplicity of use

The costs have been reduced due to the good control glyphosate offered during the first years after introduction, thereby eliminating the need for other control methods/other herbicides. When GR crop varieties were first introduced, one to two post-emergence glyphosate treatments were highly effective. Fields planted with GR crop varieties had fewer weeds than fields planted with conventional seed. Furthermore, the efficacy of ALS (acetolactate synthase) inhibiting herbicides was declining due to the development of resistant weeds that began in the mid-1980s (Benbrook, 2009). Herbicide use became 'Easier, Simpler, Cheaper'. The need for consultants to provide prescriptions for herbicide combination solutions dependent on crop type, herbicide selectivity, and weed spectrum, sometimes also varying within a farm, was eliminated. The simplicity and flexibility of the GR crop technology is one of the most important reasons for its adoption (Dill, 2005). Nowadays growers indicate that they are not interested in new weed management solutions unless they are 'easier, simpler and cheaper' than the GR crop technology package (pers. comm. Mortensen).

Before the introduction of herbicide resistant crops, farmers had to carefully select among a range of herbicide active ingredients and carefully manage the timing of herbicide application while also integrating non-chemical control practices (Mortensen *et al.,* 2012). Glyphosate, the active ingredient of the Roundup Ready herbicide, is a very effective, broad-spectrum herbicide. It is phytotoxically active on a large number of weed and crop species across a wide range of taxa (Mortensen *et al.,* 2012). Glyphosate resistant crops are engineered to express enzymes that are insensitive to or can metabolize glyphosate, and currently enable farmers to easily apply this herbicide in soybean, maize, cotton, canola, sugar beet, and alfalfa and to control problem weeds without harming the crop (Duke & Powles, 2009). Since the first introduction the number of herbicide active ingredients commercially available and applied by growers has declined (Owen, 2008, Stachler *et al.*, 2011). Glyphosate use on the other hand has increased considerably. Since the introduction of GM varieties the use of glyphosate increased with 39% in maize, with 199.8% in cotton and with 97.6% in soybean (Table 5).Table 5 Four years after the introduction of GR crops the number of post-emergence glyphosate treatments to control weeds started to increase due to the development of herbicide resistant weeds (Benbrook, 2009).

After loss of patent rights in 2000, the price of glyphosate was reduced significantly (by 40% in the USA) as generic manufacturers began to produce and market glyphosate. Additionally, in order to compete with cheap glyphosate, the price of other herbicides that can be used with GR crops was reduced after the introduction of these crops, indirectly reducing the costs of weed management to farmers using these herbicides. On top of that, the use of GR crops benefits no till or conservational tillage systems (see section on tillage above), reducing the costs even further (Duke & Powles, 2009). However, these economic benefits of GR crops are now being threatened by the evolution of herbicide resistant weeds (see section on weed resistance below).

Table 5. Changes in glyphosate use in maize, cotton and soybean in the USA in the period 1996-2007. Source: Benbrook, 2009.

Crop and period	Increase of glyphosate use (% change)	Increase of glyphosate use (pounds a.i. per acre)
Maize (1996-2005)	39%	0.27
Cotton (1996-2007)	199.8%	1.26
Soybean (1996-2006)	97.6%	0.67

Figure 6 shows the application of herbicides to soybean and the percentage of herbicide-resistant soybean. The adoption of GM soybean exceeded 90% in 2009. The strong correlation between the rising percentage of HR soybean acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests (but does not confirm) causation between these variables (National Research Council, 2010). Glyphosate is often applied in higher doses and with greater frequency than the alternative herbicides. Thus, the actual amount of herbicides per acre individually increased from 1996 to 2007 in soybean (Figure 6) and cotton (Figure 7) and only slightly decreased in maize (Figure 8). Many of the alternative herbicides are however less benign than glyphosate.

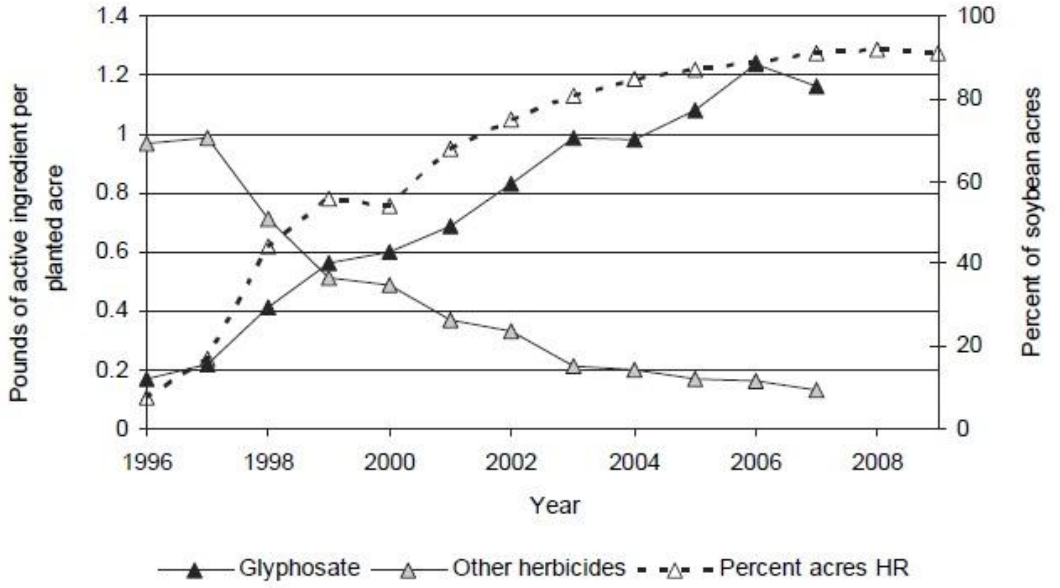

Figure 6. Application of glyphosate and other herbicides to soybean and the percentage of acres grown with HR soybean. Source of graph: National Research Council, 2010, original data not available.

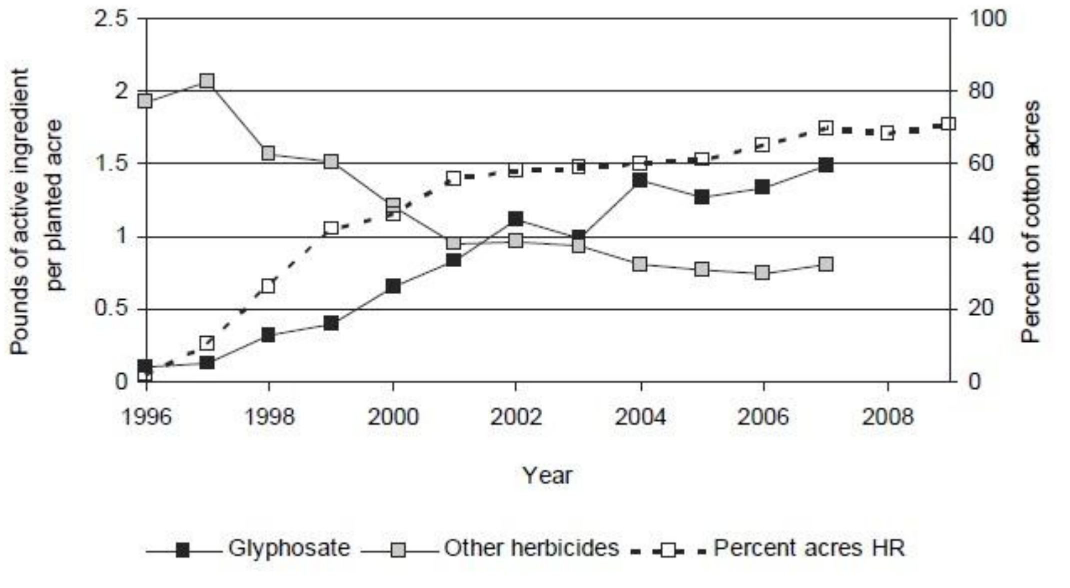

Figure 7. Application of glyphosate and other herbicides to cotton and the percentage of acres grown with HR cotton. Source of graph: National Research Council, 2010, original data not available.

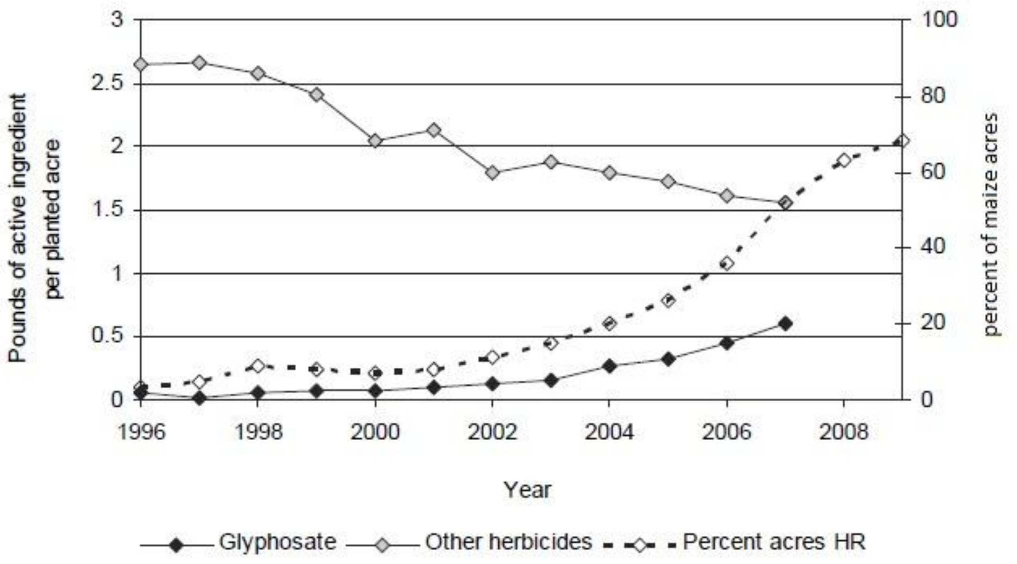

Figure 8. *Application of glyphosate and other herbicides to maize and the percentage of acres grown with HR maize. Source of graph: National Research Council, 2010, original data not available.*

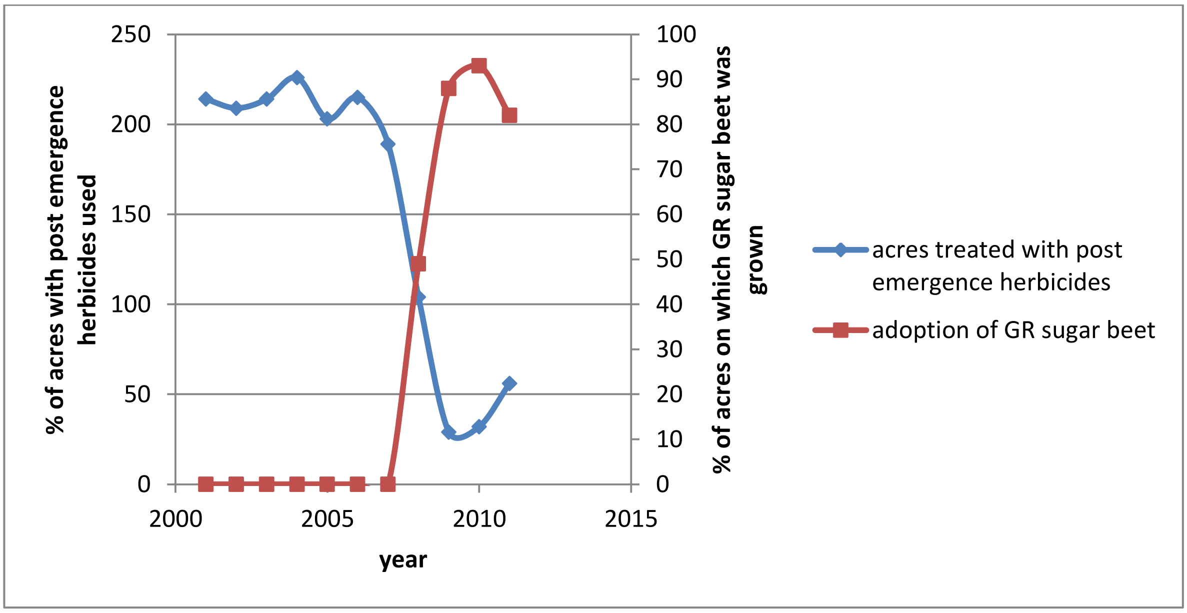

Figure 9. *Application of post emergence herbicides to sugar beet and the percentage of acres grown with Glyphosate resistant sugar beet in the states North Dakota and Minnesota. Post emergence herbicide acreage is the cumulative number of acres treated with a herbicide. Source: Stachler et al, 2011.*

Although GR sugar beet was only commercially introduced in 2008, large changes in weed control methods and quantities in sugar beet can already be observed. Figure 10 shows the fast adoption of glyphosate resistant sugar beet in Minnesota and Dakota (Stachler *et al.*, 2011). These two states, together with Idaho and Michigan account for 82% of sugar beet production in the USA (McGinnis *et al.,* 2010). The same graph shows that the total amount of acres treated with post-emergence herbicides started to decrease around the time that the adoption of GR sugar beet started. Percentages of over 100% indicate multiple treatments per year per acre on average. The use of non-chemical weed control methods shows the same trend: the use of the rotary hoe started decreasing after the introduction of GR sugar beet.

Insecticide Use

Since the introduction of Bt crops in 1996 the amount of insecticides used decreased (Figure 10). The first Bt maize introduced was for control of the European Corn Borer, *Ostrinia nubilalis*. Because chemical control of this pest was not always profitable many farmers chose to accept yield losses instead of the introduction of Bt maize. For those farmers, the introduction of Bt maize resulted in higher yields, and not in reduction of insecticide costs (Fernandez-Cornejo & Caswell, 2006). In 2003, a new type of Bt maize was introduced that protected crops against Western Corn Rootworms, *Diabrotica* spp., which were previously controlled with chemical insecticides and crop rotation. The introduction of this Bt maize has resulted in the reduction of chemical insecticide use (Fernandez-Cornejo & Caswell, 2006).

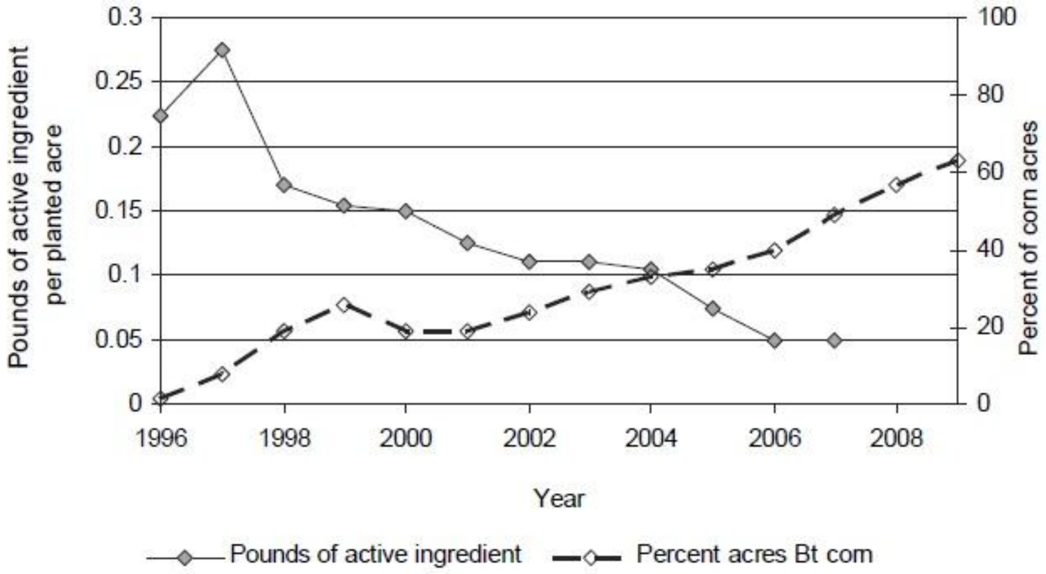

Figure 10. The amount of chemical insecticide used in maize in the USA and the percentage of acreage planted with Bt maize as the total of maize acreage. Source of graph: National Research Council 2010, no original data available.

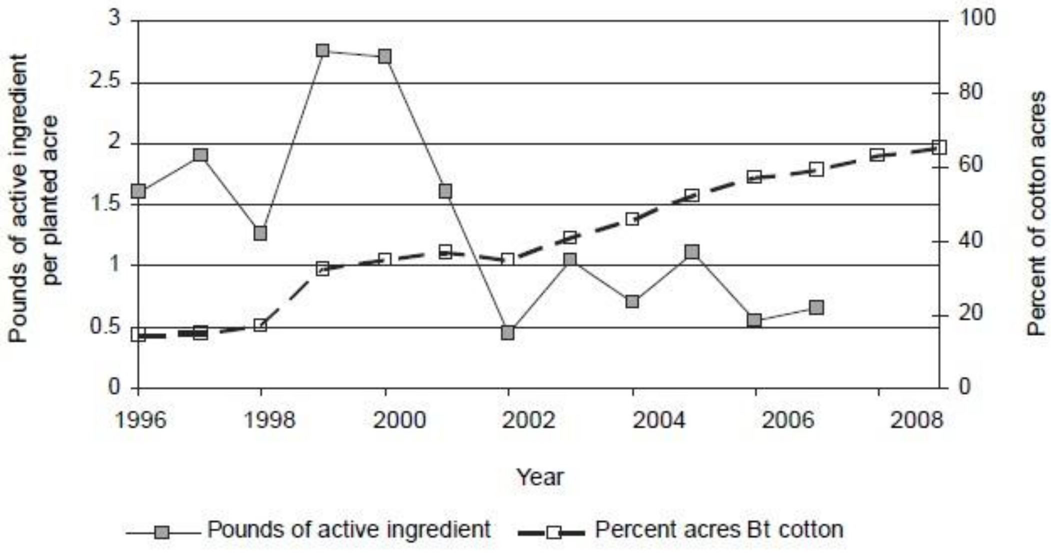

Figure 11. The amount of chemical insecticide used in cotton in the USA and the percentage of acreage planted with Bt cotton as the total of cotton acreage. Source of graph: National Research Council 2010, no original data available.

Traditionally, insects are a larger problem in cotton than in maize, and as a result cotton has a higher adoption of Bt cultivars than maize (National Research Council, 2010). As a result, the use of insecticides in cotton instead of the introduction of IR varieties was higher compared to maize and adoption of IR varieties was higher (Figure 11). Insecticide use has decreased since the introduction of Bt cotton (in amount of active ingredient per acre), but fluctuations in total cotton insecticide use have also been strongly affected by the boll weevil eradication programme (Fernandez- Cornejo *et al.,* 2009). Since the 1970s cotton growers and government have worked toward eradicating the boll weevil, a beetle that affects cotton and is not directly affected by Bt cotton. This program typically entails the heavy application of insecticides in the first year, followed by careful monitoring in the following years. Treatment in the following years takes place only when necessary. In 1999, a new wave of cotton growers began participating in the program, and partly explains the peak in insecticide use in 1999 and 2000 (Fernandez- Cornejo *et al.,* 2009). According to a USA potato growers' survey in 1998, the number of insecticide applications in Bt potatoes was 1.35 times lower while the Bt potatoes required 0.54 kg/ha less insecticide active ingredients. Based on the estimated 4% market share of Bt potatoes, EPA estimated a benefit to growers of $23 per ha or $ 500,000 nationally, resulting in 36,000 fewer acre treatments (Shelton *et al.*, 2002).

Since the introduction of Bt crops in 1996 the use of synthetic insecticides has decreased. The total amount of active ingredient insecticide applied decreased with approximately 78% in maize and 63% in cotton.

Resistance

Weeds

Agricultural practices impart selection pressure on weed communities that inevitably result in weed population shifts (Mortensen, Bastiaans & Sattin 2000). Globally, weed populations have been under selection pressure by herbicides for several decades (Duke & Powles, 2009). Before the introduction of HR crops, herbicide resistant weeds also developed. The first major wave of herbicide resistance began in the 1970s and involved 23 weed species resistant to atrazine and related herbicides of the photosystem II inhibitor class. The second major wave began in the 1980s, and involved 37 weed species resistant to acetolactate synthase enzyme (ALS) inhibitors (Benbrook, 2009). Glyphosate was introduced in 1974 and for the next 22 years there were no confirmed reports of resistance. A few isolated populations of resistant weeds emerged in the late 1990s, attributable to intensive glyphosate use in orchards or wheat production systems (Benbrook, 2009). The number and extent of weed species resistant to glyphosate has increased rapidly since 1996, with 21 species now confirmed globally (Heap, 2012). Although several of these species first appeared in cropping systems where glyphosate was being used without a resistant cultivar, the most severe outbreaks occurred in regions where GR crops were grown and facilitated the overuse of this herbicide (Heap, 2012). The list includes many of the most problematic agronomic weeds, such as *Amaranthus palmeri, Conyza Canadensis* and *Sorghum halepense* (Heap, 2012).

The speed at which the resistance of weed populations shift depends on the selection pressure imparted. The adoption of glyphosate resistant (GR) crops does not directly impart selection pressure on the weed community. However, the production systems used in GR crops increase selection pressure on the weed community due to the predominance of conservation tillage combined with glyphosate use and the limited number of other herbicides used to control weeds. Conservation tillage keeps all the weed seeds in the top of the soil, while inversion tillage ploughs seeds into deeper soil layers in one year and brings them back to the surface in the following years. In conservation tillage, weeds are exposed to the herbicides each consecutive year, instead of once every two years as is the case with inversion tillage. According to Owen (2008) the most influential selective forces that act on a weed community are tillage (disturbance) and management tactics specifically aimed at weed control, such as herbicide regimes (Owen, 2008). When weed population density and diversity are low, the impact of a single weed management tactic on that specific species will be larger (Owen, 2008).

In the case of the GR varieties, single glyphosate applications in soybean during the first years of application resulted in weed communities with lower densities, but higher diversity than in the conventional varieties (Owen, 2008). Furthermore, the pattern of glyphosate use changed across the vast maize/soybean agro-ecosystem of the

Midwestern USA after 1996 when GR crops were first grown. These two crops are often grown in continuous rotation on the same fields. This means that glyphosate is used in each field every year, often twice a year. The weed species that are able to grow in both maize and soybean are under glyphosate selection each year (Duke & Powles, 2009). The use of a single weed management tactic, lack of proper rotation and disturbance impaired a high selection pressure on the weed communities and glyphosate resistant weed species have developed quicker than they would have done under conventional varieties in which herbicides with different modes of action would have been used (Mortensen *et al.,* 2012). Additionally, since 1996 there is a rapid increase in the number of populations resistant to at least two modes of herbicide action. Currently there are 197 weed species resistant to at least 1 of the 14 known herbicide modes of action. Some of these species have multiple resistance to two or more modes of action (Heap, 2012).

The emergence and rapid spread of GR weeds has increased herbicide use in all HR crops, especially in recent years. Increasing glyphosate application rates and/or the number of applications will usually buy a little time, but invariably accelerates the emergence of full-blown resistance (Benbrook, 2009). Sometimes, the use of other herbicides with more adverse environmental effects than glyphosate is required against GR weeds. In 2011 sugar beet growers already reported several glyphosate resistant weeds in their fields (Stachler *et al.,* 2011).

Ever since the first use of herbicides resistant weeds have been reported.

The use of a single weed management tactic in GR crops, lack of proper rotation and disturbance impaired a high selection pressure on the weed communities. As a result glyphosate resistant weed species have developed quicker than they would have done under conventional varieties in which herbicides with different modes of action would have been used.

Since 1996 the number of populations resistant to at least two modes of action has rapidly increased. Currently there are 197 weed species resistant to at least 1 of the 14 known herbicide modes of action. Some of these species have multiple resistance to two or more modes of action.

Insects

Insect-resistant cotton and maize varieties are genetically modified to produce one or more truncated and activated forms of the toxins derived from the soil bacterium *Bacillus thuringiensis* (Bt). Acreage planted with Bt crops grew to 24 million ha of maize and cotton in 2010 according to Brookes & Barfoot, 2012.

Bt plant-incorporated toxins exert profound selection pressure on the development of resistant insects by virtue of the plant's continual production of toxin, in contrast to the intense but short-lived exposure of Bt insecticidal spray. Even before their commercial introduction, many scientists were concerned that Bt crops would accelerate the evolution of pest resistance to Bt toxins. As a result, Bt cotton and maize growers were required to plant blocks of conventional crop 'refuges' amidst Bt fields to help retard the development of resistance. Refuges work by maintaining populations of susceptible insects, some of which will mate with resistant insects, thereby diluting the presence of Bt-resistant genes in insect populations (Benbrook, 2009). In addition, the insects heterozygous for resistance alleles are expected to be killed by the high dose of Bt present in the IR crop (thus called the high dose-refuge strategy of insect resistance management). Furthermore, crops with multiple Bt toxins have been developed and are currently widely planted (Benbrook, 2009). The large-scale introduction of sterile insects in cotton was additionally deployed against pink bollworm (*Pectinophora gossypiella*) in Arizona (Tabashnik *et al.,* 2010). Until now, these practices have usually been effective. There are some reports on pest resistance, for instance in WCR in Iowa, which could partly be related to continuous maize cultivation and insufficient refuge planting (Gassmann *et al.,* 2011). Apart from a need for additional improvements in resistance management, stacking of different Cry genes against the same pest insect is deployed, e.g. in cotton (Downes *et al.,* 2010).

Sometimes the occurrence of secondary pests has been reported, i.e. insects insensitive to Bt that gain in importance as a consequence of the decrease of the primary pest targeted by the Bt trait. A possible example of such a pest replacement in the USA was reported by Dorhout and Rice (2010). The recent expansion of the western bean cutworm (*Striacosta albicosta*) could be related to the competitive disadvantage posed on the corn earworm (*Helicoverpa zea*), by Bt (Cry1Ab) maize. However, Hutchison *et al.* (2011) indicated that there were more ecological factors than just competition involved in the recent expansion of WBC. Another example was reported in Bt cotton. In China, mirid bugs (Miridae) increased in prominence in recent years, and was associated with lowered insecticide applications enabled by the planting of Bt cotton crops against the primary cotton pest, the bollworm (Lu *et al.,* 2010).

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Before introduction, Bt cotton and maize growers were required to plant blocks of conventional crop 'refuges' amidst Bt fields to retard the development of resistance. Furthermore, crops with multiple Bt toxins have been developed and are currently widely planted.

Until now, these practices have been usually effective. There are some reports on pest resistance and in reaction to that, the stacking of genes against the same pest insect, e.g. in cotton.

The occurrence of secondary pests has been reported, i.e. insects insensitive to Bt that gain in importance as a consequence of the decrease of the primary pest targeted by the Bt trait (in case this outcompeted the secundary pest species) or by decreased use of insecticides.

Effects on non-GM systems

The adoption of GM crops affects production costs for non-GM farmers in several ways. GM crops alter the demand for inputs (herbicides and insecticides mainly) and this affects the input costs to GM and non-GM crops alike (National Research Council, 2010). For example, the prices of insecticides that substitute for Bt decrease because of the reduced demand for these products. In other cases, GM crops increase the demand for other inputs. HR varieties increase the demand for broad-spectrum herbicides such as glyphosate, which has had mixed effects on the price. On the one hand, the increase in demand puts upward pressure on the prices of those herbicides. On the other hand, the expanded market for broad-spectrum herbicides compatible with HR crops may allow firms to reduce the price of the herbicides but they still make a profit through greater sales. HR varieties also reduce the demand for the herbicides used before the introduction of HR crop varieties became available, usually by lowering prices due to reduced demand (National Research Council, 2010).

Non-GM growers could benefit from the use of Bt crops by area-wide suppression of lepidopteran pests. Hutchison *et al.* (2010) calculated that a significant part of the economic benefit from the reduction of ECB populations in the USA went to non-GM growers.

GM maize, soybean and cotton now dominate the market in the USA. The supply of conventional, non-GM seed for these three crops is low, thus GM seeds to continue to account for the majority of acreages planted. In 2005 conventional maize, soybean and cotton seeds accounted for 36.2%, 15.9%, and 14.3% of the total seeds offered. In 2009 the shares of conventional seeds offered on the market decreased to 14.9%, 8.9%, and 12.8% for maize, soybean and cotton (source: http://www.monsanto.com/newsviews/Pages/monsanto-submission-doj.aspx#i, access date 19 October 2012).

GM crops alter the demand for inputs (herbicides and insecticides mainly) and this affects the costs of inputs to GM and non-GM crops alike.

The supply of conventional, non-GM seed has become very low.

3. Maize in the Maritime zone

This chapter describes the possible changes in the cultivation of maize after the introduction of GM varieties. Three references will be used to identify these changes: 1) the observed changes in maize cultivation after the introduction of GM varieties in the USA as described in Chapter 2.2) the current general crop cultivation practices in the Maritime zone, and 3) the traits that will be incorporated into the new varieties.

Paragraph 3.1 summarizes current cultivation practices of maize in the Maritime zone with the highest relevance for possible changes with the introduction of GM variants, paragraph 3.2 the traits incorporated in GM maize and paragraph 3.3 lists the cultivation practices most likely to change in the Maritime zone.

3.1 Current crop cultivation practices

Cultivation areas

Our reference is the present crop cultivation practice in the Maritime zone, described for instance in Kempenaar *et al.* 2003 and current cultivation manuals ('Handboek Snijmaïs', Livestock Research Wageningen UR). Within the Maritime zone there are no large differences in general maize cultivation practices. In the areas to the south and the east of the Netherlands the temperature during the growing season is higher and in some years growing conditions are dryer. In these regions, sowing will be done earlier in season and irrigation will be applied more often than in the Netherlands. More grain maize is grown than in the Netherlands. In more northern areas of the Maritime zone less maize is grown due to lower temperatures during the growing season. In the western parts of the zone (e.g. UK) growing conditions are more moist.

Maize is mainly grown for forage (silage) in the Netherlands, on about 225,000 ha in recent years. Next to this there is a small area of grain maize and corn cob mix (about 25,000 ha). Maize is mainly (80%) grown on sandy soils in the eastern and southern part of the Netherlands. The remaining area is grown on clay soils and loess soils. Maize is very often grown in a continuous cropping system, especially on fields far away from farm buildings. On fields with continuous maize cultivation weeds that are less susceptible to the mainly used herbicides are becoming more important. Sometimes maize is grown on rather wet fields. Especially in years with a great deal of rain in the autumn harvesting can be a problem on these fields and the heavy harvesting machines damage the soil structure.

Tillage and soil structure

Most sandy soils are ploughed in spring to prepare the seed bed. Clay soils are ploughed in the autumn, while the seed bed is prepared in spring. The benefits of conventional tillage are the removal of crop and weed residues and improvement of drainage and reduction of soil compaction.

Since 2006 farmers on sandy soils and loss soils in the Netherlands are obliged to grow a green manure crop after the harvest of maize. Because of the late harvest, Italian ryegrass and cereals (winter rye, winter wheat, winter barley and triticale) are mainly sown after maize. It is also possible to sow Italian ryegrass in the maize crop when maize has reached a height of 40 - 50 cm.

The green manure crop in spring is sometimes killed by glyphosate and residues of the green manure crop are ploughed into the soil. Sometimes the green manure crop is not treated with glyphosate before ploughing. Some farmers will harvest the green manure crop in spring and will plough the stubble into the soil after killing the re-growing stubble with glyphosate.

Conservation/no tillage is seldom practiced yet in the Netherlands. On-going experimentation is taking place with several systems, but up to now, there are several disadvantages to no tillage: higher weed pressure, increased susceptibility to *Fusarium*, *Helminthosporium* and eyespot (*Kabatielle zeae*) and slightly lower yields. Conservation tillage is mainly attractive in areas where the risks of soil erosion are lareger, such as slopes in the southern part of the Limburg province and in different area's in Germany, Belgium and France. It is also attractive on soils that become wet in the autumn. If the soil is not ploughed and residues of the preceding crop remain in the top soil, the field can be harvested easier with heavy machines.

Maize production particularly around the time of flowering, can be affected during periods of drought on sandy soils in the south and east part of the Netherlands and they will be irrigated when economically feasible. Maize in France, Belgium, southern Germany, and Austria is frequently irrigated.

Weed control

On most fields weeds are controlled with herbicides. The herbicides choice depends on the weed species occurring in the field. Before emergence, the following herbicides are used: isoxaflutole (Merlin), S-metolachlor (Dual Gold) and dimethenamid-P (Frontier Optima). On most fields, chemical weed control is done by spraying one or two times after emergence of the seedlings. After emergence mixtures of the following herbicides are used: terbutylazin, bromoxynil, bentazon nicosulfuron, sulcotrione, mesotrione, tembotrione, topramezone, fluroxypyr and florasulam. Potato volunteers are controlled with sulcotrione and mesotrione. Rimsulfuron (Titus) is used to control *Elytrigia repens*. However, different maize varieties are damaged by this herbicide and other sulphonylurea containing herbicides. *Calystegia sepium* is controlled by dicamba or fluroxypyr/florasulam. Sometimes mechanical weed control is carried out. There are different herbicides (tembotrione, tritosulferon and clopyralid) that are persistent in the soil and that are not allowed in certain areas where drinking water is produced. Various herbicides also cause damage in the crops grown following maize. If mesotrione or sulcotrione are used, damage can occur in sugar beet, peas, beans or vegetables grown in the year after maize. Also topramezone can cause damage in sugar beet following cultivation of maize. There are various herbicides that cannot be used when Italian ryegrass is sown in maize (e.g. dimethenamid-P (Frontier Optima)). The availability of herbicides however, is subject to regulatory changes and therefore varies from year to year.

Insect control

There are a few problems with insects in maize, mainly with fruit fly (*Oscinella frit*) and click beetles (*Agriotes* spp.). Seed treatments with insecticides are used against these insects (methiocarb, which is applied in particular to repel birds and Gaucho (imidacloprid)).

3.2 Traits incorporated into GM maize

In maize, both transgenic herbicide resistances (HR) and insect resistances (IR) are commercially available and have been grown for some 15 years in the Americas (see Chapter 2).

Herbicide resistance

The most widely used HR is glyphosate resistance (GR, also called Roundup Ready© or RR) based on an adapted form of the EPSPS enzyme, from *Agrobacterium tumefaciens* CP4, which is targeted by glyphosate,. Pioneer has an alternative version of glyphosate-tolerant maize deregulated in the USA, the Optimum® GAT®. The GAT is responsible for inactivating glyphosate; the Optimum trait confers tolerance to herbicides of the ALS inhibitor class. Another available HR is for glufosinate (Liberty Link© or LL), conferred by adapted pat or bar genes from *Streptomyces* bacteria. In view of herbicide resistance development in weeds, Dow Agrosciences developed transgenic synthetic auxin HR crops (Wright *et al.,* 2010) to widen control options. A maize version (DAS-40278-9) was deregulated in the USA in 2011 (GM Approval Database: http://www.isaaa.org/gmapprovaldatabase/default.asp). Up to now, none of the transgenic HR crops are allowed for cultivation in the EU.

Insect resistance

Commercially available transgenic IR crops are presently all based on adapted *Cry* proteins from *Bacillus thuringiensis* (usually called Bt crops). The most common variants are targeted against the lepidopteran pest European corn borer (ECB, *Ostrinia nubilalis*, 'maïsstengelboorder'), using Cry1Ab (e.g. MON810), or the coleopteran pest, western corn rootworm (WCR, *Diabrotica virgifera*, 'maïswortelkever'), using Cry3Bb1 (e.g. MON88017). MON810 is the only IR event allowed for cultivation in the EU and maize varieties containing this event are mostly grown in Spain and to a lesser extent in other European countries, such as Portugal and the Czech Republic. The Czech Republic is part of the Maritime zone. With climatic change, ECB is likely to increase in the southern part of the Maritime zone (Kocmánková *et al.,* 2010). Transgenic events against WCR are not allowed for cultivation in the EU, but the insect already occurs in southeast Europe and is currently expanding (Dillen *et al.,* 2010). WCR has also been occasionally found in the Netherlands (for the last time in 2005, although WCR was reported just across the border at Venlo in Germany in 2010). It is then treated as a quarantine organism, which up to now has led to successful eradication. Two modelling approaches indicated various degrees of northward advancement of future climatic favourability for the occurrence of WCR, and in one variant, there was overlap with the southern part of the Maritime zone (southern and eastern Germany and the Czech Republic) (Aragón & Lobo, 2012). Combinations of one or more HT and IR traits, so called stacked varieties, have increasingly become popular in commercial cultivation.

Drought tolerance

The only type of abiotic stress tolerance deregulated in the USA to date is a drought tolerant maize by Monsanto. This maize was tested in demonstration field trials in 2012 on about 4,000 ha across the Western great Plains. Drought tolerance is conferred by the expression of an RNA chaperone protein, CSPB, from *Bacillus subtilis* (MON87640) (Castiglioni *et al.,* 2008). An application for approval for import and processing as food and feed (but not for cultivation) was submitted in the EU in 2009 (http://www.gmo-compass.org/eng/gmo/db/85.docu.html).

Output traits

Several output traits have been deregulated outside of Europe: a built-in thermo-stable alpha-amylase for increasing the effectiveness of starch degradation in ethanol production and enhanced lysine contents for improving feed quality. In addition, a maize containing phytase to improve phosphorus availability in animal feed, has been approved in China in 2009 (GM Approval Database: http://www.isaaa.org/gmapprovaldatabase/default.asp). The only application for approval for import and processing as food and feed (not for cultivation) has been submitted for the lysine-enhanced maize (event LY038) in the EU, but has been withdrawn (http://www.gmo-compass.org/eng/gmo/db/85.docu.html). Thus, it is not likely that output traits will be grown soon in the EU; moreover, they will not generally have significant effects on methods of cultivation.

3.3 Cultivation changes likely to occur in the Maritime zone

In this paragraph we will focus on those cultivation practices that will most likely change after introduction of GM maize varieties in the Maritime zone. We will use both the above described current cultivation practices, the cultivation practices that changed in maize cultivation in the USA after introduction of GM maize and the above mentioned traits.

Weed control

A large part of weed control in maize, can be achieved mechanically. Nevertheless, there are incentives to prefer chemical means of weed control ('easier, simpler, cheaper', see Chapter 2); partly due to the fact that much of the cultivation work in maize is done by contractors. This can be illustrated by developments with the 'cross-compliance' arrangement, which made mechanical weeding and low herbicide use compulsory in order to qualify for subsidy. This significantly brought down herbicide usage, but since the regulation stopped in 2005, herbicide use has gone up again. There is a tendency to replace mechanical pre-treatment by relatively persistent soil herbicide pre-emergent treatments which maize can tolerate relatively well, i.e. isoxaflutool (Merlin), S-metolachloor (Dual Gold) or dimethenamid-P (Frontier Optima). A working group is presently looking into economically feasible alternatives in order to reduce herbicide usage (Kroonen-Backbier, 2011).

Although maize cultivation in Europe is not on the large scale as in the USA, it can be envisaged that maize growers in the Maritime zone would be interested in HR maize for the possibilities of its use after sowing of maize. Concomitantly, there would be a shift towards the use of glyphosate as well. Maize is usually grown without crop rotation, particularly by livestock producers. For that reason, growers must already be aware of herbicide resistance development in weeds. This problem will become more acute with HR maize, as the sole reliance on glyphosate in the USA have shown (see Chapter 2). However, their easy use is not the only reason for the adoption of HR varieties as stated above. The costs or cost savings are equally important to farmers. The combined costs of traditional maize seeds and pre-emergence herbicides other than glyphosate were lower than the costs of GR maize seed and glyphosate application. Thus the adoption of GM maize varieties that were only resistant to herbicides was not very high in the USA. Only after the introduction of stacked hybrids resistant to both herbicides as well as insects, did the adoption increase significantly. Therefore, although farmers in the Maritime zone could be interested in HR maize, the costs of the seeds and alternative herbicides will probably play an important role in the scale of adoption. The introduction of HR maize will reduce the use of herbicides that are less friendly to the environment. Some traditional herbicides are rather persistent and can affect the crop grown after maize. This problem will be reduced if glyphosate is used, because it is not persistent in soil and will have no effect on crop rotation.

Another scenario is the growth of a HR maize variety once every 4-5 years in a continuous growing system. It provides an opportunity to control weeds not very well controlled with traditionally used herbicides. Also the control of some problematic weeds like *Elytrigia repens* and *Calystegia sepium* may become easier. Nowadays on some fields with continuous maize growing it is necessary to spray against these weeds after harvesting the maize crop to reduce weed problems in the next year. With HR maize, control of these problematic weeds can be done in the maize crop. When rotation with other crops is not economically feasible, the rotation could be envisaged of GM glyphosate resistant maize with conventional maize or HR maize resistant to alternative herbicides now being developed in the USA.

Tillage, green manure crops and harvest

The introduction of HR maize is one way to enhance the possibilities to introduce no-tillage or reduced tillage. Especially in areas with a higher risk of soil erosion (e.g. in Germany, France and Austria), reduced tillage can be a tool to reduce soil erosion problems. In some areas in the Maritime zone, soils contain many stones that can damage tillage equipment. The introduction of HR maize will promote reduced tillage, especially in these areas.

Besides the perceived increased ease of weed control, the introduction of GR maize in the Maritime zone may affect other aspects of maize production as well. These aspects are the cultivation of green manure crops after maize and soil structural damage during harvest. Since 2006 farmers in the Netherlands are obliged to grow a green manure crop on sandy soils and loss soils after the harvest of maize. It is also possible to sow green manure crops during maize growth or after harvest. The introduction of HR maize in continuous maize production would make the management of green manure crops easier. In spring, the green manure crop is ploughed into the soil before a new maize crop can be sown. This is sometimes done without killing the green manure crop with glyphosate. If ploughing the green manure crop into the soil is not completely successful there is a risk of regrowth in the succeeding maize crop. If HR maize is used however, this regrowth can be easily killed with a herbicide in the maize crop. If the green manure crop is harvested in spring, most farmers would like to kill the stubble with glyphosate. To get a good killing, it is necessary to wait with spraying glyphosate until there is some regrowth. This delays the sowing of maize however. Alternatively, if the farmer would use HR maize sown on strips, it could be possible to sow maize immediately after the harvest of the green manure crop, thus without delaying sowing.

Interest in conservation tillage has already been shown by experiments in Europe, but conservation tillage has some drawbacks due to problems with weeds, diseases and yields. When grown without rotation, conservation tillage will lead to a high level of maize crop residues in the soil, which could increase problems with fungal diseases, such as *Helminthosporium,* eyespot and *Fusarium.* Nevertheless, introduction of HR maize could be expected to facilitate conservation tillage in the Netherlands as well. For instance, it could be attractive on soils that are relatively wet in the autumn which often suffer from soil structural damage during maize harvest. To prevent soil structural damage it would be beneficial to have crop residues in the top layer of the soil. One way of achieving this, is to grow maize following grassland. This rotation is currently very difficult, because grass cannot be killed with herbicides after the sowing of maize without damaging the maize crop. The current options are to plough the grass deep into the soil or to chemically kill the grass before sowing maize. The latter will postpone the sowing date of maize and lead to yield loss. If HR maize were to be grown, the grass could be killed with herbicides after sowing the maize, without causing yield losses. The killed grass residues will then remain in the top layer of the soil and reduce harvesting problems in the autumn. There will be less risks of damage to soil structure by heavy harvesting machines.

Insect control

European Corn Borer occurs in the warmer parts of Europe, including the southern part of the Maritime zone and might increase with climate warming. WCR (Western Corn Rootworm, *Diabrotica*) has been occasionally found in the Netherlands, but is immediately subject to a strict eradication programme. If WCR would become established through climate warming in at least the southern part of the Maritime Zone, Bt maize (containing an event such as Cry3Bb, e.g. MON88017) would become interesting. It would make the adoption of the stacked hybrids more likely.

With regard to effects on insecticide usage, little insect control is presently necessary in maize cultivation in the region. Therefore, most of the possible effects of Bt maize introduction can only be inferred theoretically. Dillen *et al.* (2010) have described presently used alternatives for Bt maize against WCR in Europe, i.e. crop rotation, seed treatment and application of soil insecticides. Of these options, seed treatment is already used with maize in the Netherlands (see 3.1). However, as seed treatment may be less effective with high larval incidences, soil insecticides, although not always fully effective, are particularly in use in continuous maize cultivation. However, the choice of soil insecticides is limited in the EU due to environmental considerations (Dillen *et al.,* 2010). Overall, a significant avoidance of insecticide use could be hypothesized for the introduction of Bt maize in view of its attractiveness as a growers' strategy to control WCR.

Bt maize comes with a particular need for resistance management to avoid resistance development in the insect pest, but the usual high dose/refuge strategy has been shown to be feasible in the large-scale USA agriculture (Tabashnik *et al.,* 2009).

Irrigation

For the first deregulated transgenic event conferring drought tolerance on maize, MON87460**,** a first indication of its effectiveness under normal commercial production will come from demonstration trials on 4000 ha of farmland in the Midwest of the USA this year (2012). In the Netherlands, forage maize production can be affected during periods of drought at the time of flowering on sandy soils and will sometimes be irrigated (Kempenaar *et al.,* 2003). If the MON87460 maize would work under NW European conditions, the need for irrigation on sandy soils is expected to diminish. When yields under non-stress conditions are indeed essentially the same as other elite maize varieties, no change in other cultivation aspects, such as fertilization and crop protection, would be expected.

After the introduction of GM maize varieties the following cultivation changes are likely:

- The introduction of GR maize will most likely reduce the application of some traditional, rather persistent herbicides. The risk of the development of glyphosate resistant weeds will increase when GR maize is grown in a continuous maize rotation without proper resistance management.
- The introduction of HR maize could make the management easier of green manure crops grown after maize. If the green manure crop regrows in the succeeding maize crop it could be easily killed by the herbicide. If maize is sown after grassland or after a green manure crop harvested for fodder, HR maize could be sown in strips and the green manure stubble be killed after emergence of the maize crop. This possibility could lower the risk of postponing sowing and thus reducing maize yield.
- Conservation tillage will be more likely in HR maize than in conventional maize, especially in areas with soil erosion. The current bottleneck for these systems are soil structure problems. Soil structure damage during harvest can be prevented by keeping grass residues in the top soil layer. In HR maize the grassland could be killed after sowing maize without the need to plough or the risk of maize yield loss due to herbicide damage.
- IR maize is resistant against insects that are currently neither widely distributed in the Maritime zone nor cause a lot of damage. However, when their population sizes or distribution area increase, the adoption of IR maize could be a serious option in the Maritime zone, accompanied with the avoidance of synthetic insecticides.
- The introduction of maize varieties containing the transgenic event conferring drought tolerance is not expected to change cultivation aspects other than the reduction of the need for irrigation.

4. Sugar beet in the Maritime zone

This chapter describes the possible changes in cultivation of sugar beet after the introduction of GM varieties. Three references will be used to identify these changes: 1) the observed cultivation changes in sugar beet after the introduced GM varieties in the USA as described in Chapter 2, 2) the current general crop cultivation practices in the Maritime zone, and 3) the traits that will be incorporated into the new varieties.

Paragraph 4.1 summarizes current cultivation practices of sugar beet in the Maritime zone with the highest relevance for possible changes with the introduction of GM variants, paragraph 4.2 the traits incorporated in GM sugar beet and paragraph 4.3 lists the cultivation practices most likely to change in the Maritime zone.

4.1 Current crop cultivation practices

Cultivation area

Our reference is the present crop cultivation practice in The Maritime zone described in Kempenaar *et al.* 2003 and current cultivation manuals ('Teelthandleiding Suikerbieten (Betatip)', IRS). In general, cultivation practices in the Maritime zone are quite similar to each other. In countries to the south and east of the Netherlands (France, Germany, Austria) more irrigation is required than in the Netherlands. The estimated sugar beet area in the Maritime zone is 1,200,000 ha, of which 75,000 ha in the Netherlands, 60,000 ha in Belgium, 400,000 ha in France, 400,000 ha in Germany, 50,000 ha in Austria, 120,000 ha in the UK and 90,000 ha in Scandinavia. About 65% of the sugar beets in the Netherlands is grown on clay soils and loess soils and 35% on sandy soils and reclaimed peat soils. Sugar beet is grown in rotation with other crops, like cereals and potatoes in a frequency of at least one time in four years.

Tillage

Ploughing is the norm in most sugar beet rotations in the Maritime zone (May, 2003; Kempenaar *et al.*, 2003). Clay soils are usually ploughed in the autumn and the seed bed is prepared after winter. If potatoes were grown the year before, tillage in the autumn is sometimes restricted to slight cultivation such that the remaining tubers are left on the soil or in the upper layer of the soil. In this way tubers that could lead to weed problems, as volunteers in the following growing season, can become frozen during winter. Sandy soils are ploughed in spring. On some sandy or peat soil fields barley is sown between the rows of sugar beet to prevent wind erosion.

Experimentation on a very limited scale has been performed in the Netherlands with reduced tillage before the sowing of sugar beet. Instead of inverting the soil by means of ploughing, tillage was restricted to loosening the soil to a depth of about 20 cm with chisels or sweeps. Especially on the fields on the loess soils reduced tillage is promoted because of the risks of erosion. In other regions of the Maritime zone where soil erosion is a problem (on slopes and on fields with light soils (wind erosion)), reduced tillage is applied on a limited scale. Other reasons to promote reduced tillage are: reduced energy (fuel) use, less labour, less maintenance of machines, less loss of nutrients and pesticides from the field also resulting in less water pollution, reduced loss of carbon from the soil. In sugar beet growing to date, it is not clear whether these reasons are attractive enough to introduce reduced tillage on flat fields. Moreover, it is not known if reduced tillage will increase disease and pest problems at emergence. It is possible that more damage by insects or mice occur after reduced tillage, for example after cereals. There are some possibilities to optimize reduced tillage systems in sugar beet. The limited number of experiments showed that sugar beet yield was slightly or unaffected after ploughing.

Weed control

Weeds in sugar beet crops are mostly controlled with herbicides. Weed control is important in sugar beet because it is very sensitive to competition from weeds that emerge before the six-eight leaf stage of the crop (Scott *et al.*, 1979). Depending on the soil and weather conditions three to four sprayings are carried out after emergence of the seedlings. Herbicides used are metamitron, ethofumesate, phenmedipham, desmedipham, clopyralid, and a few minor ones, incl. triflusulphuron. The choice of the herbicides depends on the occurrence of the weed species. Sometimes a soil herbicide is applied before emergence, e.g. metamitron and chloridazone. After potatoes, it is often necessary to apply glyphosate on different spots in the field to control potato volunteers. On fields where grass weeds are important, herbicides that control grasses are added to the herbicide mixture. For example quizalofop-p-ethyl (Targa Prestige). Usually mechanical weed control in addition to the herbicide treatments is required in sugar beet. In several countries of the Maritime zone such as the Netherlands, the UK and Germany, mechanical control between the rows is performed (on about 25% of the fields in the Netherlands). In the United States farmers growing conventional sugar beet supplement their herbicides treatments with mechanical weed control as well (McGinnis *et al.*, 2010).

Insect control

In general, insect pests are not a major problem in sugar beet nowadays in the Maritime zone of Europe. *Myzus persicae* is an important insect pest, because of the transmission of Beet Yellow Virus (BYV) and Beet Mild Yellowing Virus (BMYV). However, in general, seed treatments with systemic insecticides, like thiamethoxam or betacyfluthrin and clothianidine, are providing sufficient protection against *Myzus persicae*. If untreated seed is used, *Myzus persicae* can be controlled by spraying thiacloprid or pirimicarb. Other insects like *Agrotis* spp., *Chaetocnema concinna, Chaetocnema tibialis, Blitphaga poaca, Atomaria linearis, Pegomya betae* and *Aphis fabae* can occasionally cause damage to the crop.

4.2 Traits incorporated into GM sugar beet

The only transgenic trait presently incorporated into commercially available sugar beet is herbicide glyphosate resistance (RR), conferred by event H7-1 (McGinnis *et al.,* 2010). Like in maize (section 3.2), the glyphosate tolerance is based on an adapted EPSPS enzyme from *Agrobacterium tumefaciens* CP4. The H7-1 sugar beet showed an unprecedented adoption rate in the USA (95% of the total acreage within three years after commercialization, James, 2011).

4.3 Cultivation changes likely to occur in the Maritime zone

In this paragraph, we will focus on those cultivation practices that will most likely change after introduction of the GM sugar beet varieties in The Maritime zone. We will use both the above described current cultivation practices, the cultivation practices that changed in sugar beet cultivation in the USA after introduction of GM sugar beet and the above described trait.

Weed control and crop rotation

As weed control in sugar beet is not easy, interest in HR sugar beet may be expected in the Maritime zone, particularly in view of the unprecedented rapid adoption rate in the USA. For instance, control of potato volunteers could become more efficient, because these plants are easily controlled with glyphosate. In addition, it could provide the option of using herbicides to combat weed beet (*Beta vulgaris*), which, being conspecific with sugar beet, essentially has the same levels of sensitivity to herbicides as sugar beet. In the UK fields that are severely infested with the weed beet have to be taken out of sugar beet production, the adoption of RR sugar beet would allow those fields to return growing the crop (May, 2003).

The introduction of RR sugar beet will most likely reduce the number of applications of herbicides from 3-5 times down to 1-3 times and reduce the need for mechanical weed control. A normal herbicide regime for conventional sugar beet in the USA encompassed three to four applications of combinations of phenmedipham, desmedipham, ethofumesate, clopyralid, triflusulphuron and clethodim, most of which are also used in German and Dutch sugar beet fields, together with metamitron and a few little used ones (Schütte & Mertens, 2010). However, in 2010 just two applications of only glyphosate were performed in the USA. In addition, one or two mechanical weed control treatments are applied in the USA, and in some areas with high weed infestation, even labour is used for weeding. In the RR sugar beet, additionally one cultivation was applied in 2008 (Khan, 2010). Weed control will become easier and less dependent of weather conditions. Farmers can delay spraying RR sugar beet to await suitable soil conditions, which would reduce the risk of soil structure damage from spray operations. In some seasons this would remove the need to subsoil after the beet crop to correct soil structure where the sprayer has passed frequently (May, 2003). The current selection and use of treatments from the abovementioned herbicide options requires skill and management time. The flexible timing of glyphosate treatment in beet and the fact that only one product would be required, would lessen the need for input from advisors and will not need require a careful choice of herbicides (May, 2003).

The use of RR sugar beet is likely to alter weed control elsewhere in the rotation as well. *Cirsium arvense* (creeping thistle) is a species that is difficult to control chemically in sugar beet without causing damage. These thistles are insufficiently controlled in sugar beet, and will contaminate the following crop. Sugar beet is often grown in rotation with cereals, in which this thistle is a large problem. Creeping thistle could be reduced by spraying in RR sugar beet at the appropriate time without damaging the sugar beet. This will most likely reduce or remove *C. arvense* densities in following crops such as cereals, reducing the need for control (May, 2003). In order to suppress the development of glyphosate resistance in weeds, sugar beet needs to be rotated with conventional crops such as wheat or barley, or the application of a conventional herbicide in a rotation with GM maize as in the USA (Khan, 2010). Rotation is a normal part of beet cultivation in the Netherlands and the Maritime zone of Europe as a whole. For weed beet, there is a specific risk of glyphosate resistance, namely through hybridization with HR sugar beet. There are two main routes for weed beet to obtain the HR transgene through hybridization: (1) outcrossing of weed beets already present in the beet cultivation areas with bolters from the HR sugar beet cultivar; (2) HR hybrids in the sowing seed lots arisen by outcrossing of an HR sugar beet mother line with a weed beet or sea beet in the seed production areas. Sea beets are localized in the Mediterranean region and slightly overlap with the Maritime zone in the south of France. To avoid the second problem with weed beets, seed production rules are already strict in the EU and the usual aim is to keep weed beet admixture below a threshold of 0.05% (Van den Brink *et al.,* 2008). Even then, the few HR weed beets that still could reach the beet cultivation areas could lead to problems when not properly controlled. Thus, bolter control, i.e. destroying both cultivar bolters and flowering weed beets, will need to be even more strict than normal for weed beet control and for phytosanitary reasons (Van de Wiel & Lotz, 2006; Colbach *et al.*, 2010).

Tillage

The RR sugar beet allows reduced tillage, such as strip-tillage. It is difficult to predict to what extent this would also lead to reduced tillage in the Maritime zone of Europe. For instance, beet growth is sensitive to local soil compaction, which calls for ploughing to ensure proper growth of the beets. However, there are also other implements available which are able to break up compacted layers in the soil. These implements do not turn the soil over and they leave crop residues in the top layer of the soil. If the soil is tilled with these implement more weeds will be present. Weed control could be easier when HR sugar beet is grown. On the sandy and peat soils, reduced tillage could have the advantage that more crop residues are left in the top layer of the soil. This could reduce the risk of wind erosion. Sowing barley between sugar beet rows to prevent erosion during the first growth stages of the beets would not be needed any longer. In areas where soil erosion is a problem (south east of the Netherlands, areas in Germany, Belgium and France) reduced tillage in sugar beet is an interesting option to reduce erosion. This could lead to a higher adoption of RR sugar beet and reduced tillage in these areas.

Insect and disease control

None of the traits introduced in current or known future GM sugar beet varieties aims at insect or disease resistance. In that respect the introduction of these GM sugar beet varieties is not likely to alter any insecticide and fungicide use. There are reports that glyphosate usage in HR crops promotes the occurrence of some diseases. There were indications for increased susceptibility of sugar beet to soil borne fungi from glasshouse trials, but this was not observed in commercial fields in 2008 (Khan, 2010). Therefore, no differences in crop protection other than herbicide usage are expected for RR sugar beet, provided that the transgenic trait would become available in elite varieties resistant to important beet diseases, such as rhizomania, rhizoctonia and *Cercospora*.

HR sugar beet could become a good option for using herbicides to control weed beet, the most challenging weed in sugar beet. However, the cultivation of sugar beet for seed in limited areas with widespread weed beet, could increase the risk of development of herbicide resistant weed beet and its subsequent spread. This requires attention in seed production/certification and for bolter control in beet cultivation.

The number of herbicide applications during cultivation can be likely reduced from 3 to 5 times down to 1-3 times when sugar beets are grown in rotations in which several herbicides with different modes of actions are used.

Sugar beet is often grown in rotation with cereals in which perennial weed species can be problematic. Weed control in those crops can be easier when these species are controlled in the preceding sugar beet crop at the right time. HR sugar beet could make their control possible using herbicides without reducing sugar beet yields.

On sandy soils GM sugar beet varieties could be grow in conservation tillage systems, reducing the risk of soil erosion. On clay soils sugar beet would suffer from soil compaction in conservation tillage systems, making the adoption of these tillage systems unlikely. However, with implements that break up compact soil layers, it is also possible to grow sugar beet on these soils under conservation tillage systems.

None of the traits introduced in current or known future GM sugar beet varieties aims at insect or disease resistance. In that respect the introduction of sugar beet GM varieties is not likely to alter any insecticide or fungicide use.

5. Potato in the Maritime zone

This chapter describes the possible changes in cultivation of potato after the introduction of GM varieties. Three references will be used to identify these changes: 1) the current general crop cultivation practices in the Maritime zone, 2) the traits that will be incorporated into the new varieties and 3) an adapted tillage to prevent outcrossing of genetically modified characteristics or mixing of GM varieties with conventionally bred varieties.

Paragraph 5.1 summarizes current cultivation practices of potato in the Maritime zone with the highest relevance for possible changes with the introduction of GM variants, paragraph 5.2 the traits incorporated in GM potato and paragraph 5.3 lists the cultivation practices most likely to change in the Maritime zone.

5.1 Current crop cultivation

Our reference is the present crop cultivation practice in the Maritime zone described in Kempenaar *et al.,* 2003 and current cultivation manuals ('Teelt van pootaardappelen', teelt van consumptie-aardappelen' and 'Teelthandleiding Zetmeelaardappelen', PPO Wageningen UR).

Cultivation area

The total potato production in the Maritime zone takes place on about 900,000 ha, of which 150,000 ha in the Netherlands, 70,000 ha in Belgium, 160,000 ha in France, 260,000 ha in Germany, 140,000 ha in the United Kingdom and Ireland, and 100,000 ha in Scandinavian countries. In the following section the Dutch potato cultivation is used as an example to show the regional diversity in potato cultivation.
In the Netherlands potato growing is split up in three types of crops

1. Seed potatoes about 37 600 ha in 2012 (source: www.NAK.nl)
2. Ware potatoes about 68 000 ha in 2012 and
3. Starch potatoes about 43 000 ha in 2012 (source: http://www.cbs.nl/nl-NL/menu/themas/landbouw/publicaties/artikelen/archief/2012/2012-akkerbouw-voorlopige-raming-2012-art.htm).

Seed potatoes in the Netherlands are mostly grown along the northern and western coast and in the polders in the central part of the country. Total annual production volume is about 1 million tonnes. About two thirds of the total seed production is annually exported. The most important variety is Spunta with about 5 000 ha. In total more than 300 varieties are multiplied every year (source: www.NAK.nl).

Ware potatoes are grown on clay soils in the polders, in the south western region and on sandy soils in the south and south eastern parts of The Netherlands. Most ware potatoes (about 3.5 million tonnes) are processed into French fries (UK: chips) and about 70 % of the French fry production is exported. A smaller share is processed into chips (UK: crisps) and other products and a share is packed to be sold as fresh potatoes in super markets. In 2012, the most important potato varieties were Fontane, Agria, Innovator, all varieties preferred by the French fry industry. In the past Bintje was the most widely grown ware potato variety both for fresh consumption and processing into French fries but its importance is decreasing rapidly.

Starch potatoes are grown in the north eastern region (mainly in the provinces Groningen and Drenthe), mostly on sandy soils and 'reclaimed' peat soils. About 80% of the produced starch and special products made from potato starch is exported, mainly within EU and the most important variety with 32% (14 000 ha) is Seresta.

Tillage

Potatoes are rotated with other crops, like cereals and sugar beet, generally in a frequency of 1 in 3 or 4 years; the starch potato rotation is often 1:2. Clay soils are usually ploughed in the autumn and sandy and peat soils in spring. Potatoes are grown in ridges, especially to facilitate harvesting. In autumn most potatoes are stored in insulated potato stores before they are packed, exported or processed. To obtain the best quality, seed potatoes are harvested about 2 months earlier than ware and starch potatoes. Starch and ware potatoes are mainly harvested in October and November. The earlier harvest of seed potatoes is necessary to prevent them from becoming virus-infected by aphids.

Crop protection

The most important disease in potato is late blight, *Phytophthora infestans*. A large part of crop protection in potato is presently comprised of fungicides to combat late blight, usually 10-16 applications totalling on average 8.6 kg/ha of active ingredient (Haverkort *et al.,* 2009). Environmental impact has already been significantly reduced in recent years by changes in chemicals used and improved timing of application based on weather conditions favouring late blight development (Cooke *et al.,* 2011). Using a combination of critical period estimation and knowledge on cultivar resistance, spray reductions of 46-81% were experimentally feasible (Kessel *et al.,* 2010). In seed potato virus diseases and bacterial diseases are also important. Especially bacterial diseases are difficult to control. During the last years the occurrence of Colorado beetles has increased. They are currently controlled by 1 to 3 sprayings with synthetic insecticides such as thiacloprid, acetamiprid, thiomethocam or pyrethrods. A rather relevant challenge in a country where potatoes are grown in short rotations is the control of nematodes. Insect and weed control do not lead to insurmountable problems. Weed control is partly carried out with chemicals and partly mechanical, depending on soil type and farmers' preference. The occasional volunteer plants are a problem in relation to late blight, potato cyst nematode densities and the spread of virus into seed crops.

5.2 Traits incorporated into GM potato

Presently, the relatively most likely traits to become introduced into commercial cultivation in the Maritime zone are an output trait, namely a change in starch composition from a mixture of amylose and amylopectin to an amylose free potato, and a disease resistance, i.e. against late blight, through the use of R genes from related *Solanum* species.

Starch composition

A potato variety without amylose, Amflora (EH92-527-1), was allowed for cultivation in the EU in 2010. Since then, seed potato production has taken place in Germany and Sweden, but in 2012, the holder BASF decided to withdraw commercial cultivation of GM crops from Europe and thus, cultivation has not yet taken off. This is also the case with the amylopectin potato Modena (AV43-6-G7) at AVEBE, which had entered into a cooperation with BASF on GM amylose free potato. The Amflora potato is based on the introduction of an antisense version of the endogenous potato gene granule-bound starch synthase (GBSS), which inhibits the expression of the *gbss* gene. This in turn leads to a reduction in the production of amylose, leaving amylopectin as the predominant starch constituent in the tuber. Antisense technology on GBSS was also used for the Modena potato (Visser *et al.,* 1991).

Late blight resistance

Late blight resistance is being developed through the introduction of resistance (R) genes from several wild potato species cross-compatible with cultivated potato, a concept called cisgenesis (Park *et al.,* 2009). Advantages of this concept are that through transformation, the R genes can be more efficiently introduced than through conventional crossing with the wild species that they come from, and the R genes can be introduced in existing highly valued varieties. In order to suppress resistance development in the causal organism, *Phytophthora infestans*, a strategy is followed, transforming at least three different R genes into a variety (stacking) (Zhu *et al.,* 2012) and to explore resistance management options of using variants of the same variety with various combinations of R genes (cassettes) that can be alternated in crop rotation depending on the type of *P. infestans* present in the area (Haverkort *et al.,* 2008). The R genes all belong to a family of highly variable genes characterized by a nucleotide-binding site (NBS) and a leucine-rich repeat (LRR), so called NBS-LRR genes. These genes often occur in clusters in the genome. These genes widely occur among plants and are involved in disease resistance, not only against oomycetes, such as *P. infestans*, but also against viruses, bacteria, fungi, nematodes and insects (McHale *et al.,* 2006).

An early introduction of insect-resistant Bt potato (against Colorado beetle) was discontinued in 2001 (see Chapter 2.1). Two Bt potato events against coleopterans have been approved in the Russian federation in 2005 and 2007 (GM Approval Database: http://www.isaaa.org/gmapprovaldatabase/default.asp), but there are currently no applications for approval in the EU. Thus, IR potato will not be discussed in the following section, 5.3.

5.3 Cultivation changes likely to occur in the Maritime zone

In this paragraph we will focus on those cultivation practices that will most likely change after introduction of GM potato varieties in the Maritime zone. The traits expected to be introduced under 5.2 have no precedent elsewhere in the world, as the limited introduction of GM potato in the USA in the past concerned Bt and virus resistance (see Chapter 2).

Production chain

Amylose depletion is an output trait with little likelihood of changes in cultivation practices. Field trial practice did not show consistent differences in cultivation effects up till now. Management of the production chain may be different, i.e. the whole chain from seed production to processing is managed by a single company, such as Avebe.

Disease control

Late blight resistance developed according to the concept of cisgenesis (Park *et al.,* 2009) is based on R genes, which have a dominant mode of inheritance like Bt resistance genes, yet the modes of action of their respective proteins are completely different. As with Bt maize (Gómez-Barbero *et al.,* 2008) or cotton (Tripp, 2009), successful introduction of late blight-resistant potato will reduce crop protection applications, in this case the use of fungicides. By using resistant varieties, fungicide amounts are estimated to be reduced by 75% (pers. comm. Kessel).

Nevertheless, as reported earlier for e.g. Bt cotton (see Chapter 2), there may be limits to reducing fungicide use by the development of secondary pests. This is similar to the case of potato with early blight *Alternaria*.

Late blight is notorious for overcoming resistance based on R genes conventionally bred in the past. Unlike Bt crops, resistance management of *Phytophthora* is not envisaged through refuge strategies, but through pyramiding of R genes. The latter approach is also practiced nowadays in Bt cotton with the recent development of resistant pest insects (see Chapter 2). In addition, *Phytophthora* resistance management should also come from alternating varieties with different R gene combinations (cassettes). This would mean that growers and seed producers may need to plan their potato cultivations more carefully.

Apart from the crop protection management, no changes in potato cultivation are expected, since the same elite varieties as presently used will essentially form the basis of the late blight-resistant lines.

The most likely traits to be introduced into commercial potato cultivation in the Maritime zone are:

- An output trait, namely a change in starch composition from a mixture of amylose and amylopectin to amylose free, and
- A disease resistance trait, against late blight.

The amylopectin trait is an output trait with little likelihood of changes in cultivation practices.

A successful introduction of late blight-potato will potentially reduce fungicide applications up to 75%. Resistance management will be required: alternation of varieties with different R gene combinations. In addition, the reduced application of fungicides may cause the increased development of secondary pests, and reduction of fungicides may be lower in reality.

6. Discussion and conclusion

GM crop varieties grown on a commercial scale are resistant to herbicides, insects, and viruses, or a combination of these characteristics. Farmers have adopted these GM varieties for three reasons: cost savings, better (weed) management, and simplicity of use. The use of GM varieties has altered the following farmers' agronomic practices: tillage, herbicide use and weed control, insecticide use, and resistance management.

Observed general trends, based on USA data:

- Farmers who use GM HR varieties are more likely to adopt No tillage systems and vice versa: in No tillage systems farmers are more likely to adopt GM varieties.
- GM crops reduced overall pesticide use in the USA in the first three years of commercial introduction (1996-1998) by 1.2%, 2.3% and 2.3% per year, but increased pesticide use by 20% in 2007 and by 27% in 2008, compared to the amount of pesticide likely to have been applied in the absence of HR and Bt seeds. This increase can completely be attributed to the increased use of herbicides.
- Herbicide resistant weed species have developed more rapidly under GR crops than they would have done under conventional varieties in which several herbicides with different modes of action would have been used. Some of these species have multiple resistances to two or more modes of action.
- Development of resistant insects has been largely prevented with the creation of conventional crop refuges amidst Bt fields and the use of crops with multiple Bt toxins. However, there are some reports on pest resistance, for instance in WCR in Iowa, which could partly be related to continuous maize cultivation and insufficient refuge planting.

Some of these general trends will be probably relevant for the Maritime zone of Europe as well. In this chapter we give an overview of cultivation changes that could occur after introduction of GM varieties in the Maritime zone. We excluded environmental and general socio-economic effects from our analysis. These effects can however influence the cultivation of these crops as well and should be taken into account in the future.

Although there are many similarities in maize, potato and sugar beet cultivation within the Maritime zone, areas within this zone differ from each other as well. These differences, like the risk of soil erosion, temperature differences, or the occurrence of a certain pest or disease, make it very hard to provide general cultivation changes for the whole Maritime zone.

The adoption of no till or reduced tillage systems will vary between regions of the Maritime zone and will depend on the risk of soil erosion in the region. In areas like the Netherlands, the risk of soil erosion is generally low, but in some other areas of the zone the risk of erosion will be higher and farmers are more likely to switch from inversion tillage to no till systems after the adoption of GM crops.

Maize

Table 6 gives an overview of the most likely cultivation changes after the introduction of GM maize varieties containing herbicide resistance, insect resistance and drought resistance.

The introduction of GR maize will most likely reduce the application of some traditional herbicides that are rather persistent. The risk of the development of glyphosate resistant weeds will increase when GR maize is grown in a continuous maize rotation without proper resistance management.

The HR maize varieties could make weed control in maize 'easier and simpler' in the Maritime zone. However, the costs or cost savings are equally important to farmers. The adoption of GM maize also depends on the costs of the GM and conventional seeds and the price of glyphosate and alternative herbicides.

Other influential aspects may be the legal obligation to grow a green manure crop after a maize crop and the possibility to apply conservation tillage with HR maize. The use of HR maize varieties could increase the possibilities of farmers to grow a green manure crop in between two maize crops, which currently delays the sowing date of conventional maize and reduces the potential yield. With HR maize it could be possible to apply conservation tillage in which maize can be grown after grassland. Maize can be directly seeded in small strips in the grassland in which the soil is prepared for sowing, leaving the soil surface between the rows undisturbed. The grassland does not have to be ploughed deep into the soil or killed chemically before the maize is sown, but can be killed after maize emergence. This would leave grass residues in the top layer of the soil and would reduce soil structure damage during harvest in autumn. In areas that suffer from soil erosion, the introduction of HR maize may make reduced tillage feasible, reducing the risk of soil erosion.

The current available IR maize varieties are resistant to the WCR (Western Corn Rootworm) and ECB (European Corn Borer). The ECB occurs in warmer parts of Europe, and is already present in the southern part of the Maritime zone. Thus, some Bt maize (with the MON810 event against ECB) is already grown in the Czech Republic. The WCR has been reported occasionally, but is not yet a large problem, although it could enter the southern part of the Maritime Zone with climate warming. If population sizes increase, the stacked GM varieties, containing resistance against both types of insects (lepidopterans and coleopterans) as well as herbicides could gain interest. A significant avoidance of insecticide use could therefore be hypothesized for the introduction of Bt maize.

The introduction of maize varieties containing the transgenic event conferring drought tolerance is not expected to change cultivation aspects other than the reduction of the need for irrigation.

Table 6. *Overview of most likely cultivation changes after the introduction of GM Maize varieties containing different traits.*

	GM Maize varieties containing:		
Likely to change:	Herbicide resistance	Insect resistance	Drought resistance
Soil tillage	Y	N	N
Herbicide use	Y	N	N
Weed control	Y	N	N
Insecticide use	N	Y	N
Weed resistance management	Y	N	N
Insect resistance management	N	Y	N
Disease control	N	N	N
Disease resistance management	N	N	N
Fertilization	Y	N	N
Irrigation	N	N	Y

Sugar beet

Table 7 gives an overview of the most likely cultivation changes after the introduction of GM sugar beet varieties containing herbicide resistance.

Weed control in sugar beet in the Maritime zone is currently not an easy task for growers. Therefore, interest for HR sugar beet may be expected in this area of Europe. It could be a good option to use herbicides for weed beet control, the most challenging weed in sugar beet. The number of herbicide applications during cultivation is likely to be reduced from 3-5 times down to 1-3 times, when HR sugar beets are grown in rotations in which several herbicides with different modes of actions are used. However, there is a specific risk for weed beet of obtaining glyphosate resistance through hybridization with HR sugar beet, both in seed production areas mainly located outside of the Maritime zone and in the beet production areas within the Maritime zone. Therefore, strict bolter control in the beet production areas is necessary to suppress the development of transgenic HR weed beets.

Sugar beet is often grown in rotation with cereals in which perennial weed species can be problematic. Weed control in those crops can be easier when these species are controlled in the preceding sugar beet crop at the right time. HR sugar beet could make the control of these species possible with herbicides during sugar beet growth.

None of the traits introduced in current or known future GM sugar beet varieties aims at insect or disease resistance. Currently there are no large scale problems with pests or diseases in sugar beet in the Maritime zone. In that respect the introduction of sugar beet GM varieties is not likely to alter any insecticide or fungicide use.

Table 7. overview of the most likely cultivation changes after the introduction of GM sugar beet varieties containing herbicide resistance.

	GM Sugar beet varieties containing :
Likely to change:	Herbicide resistance
Soil tillage	Y
Herbicide use	Y
Weed control	Y
Insecticide use	N
Weed resistance management	Y
Insect resistance management	N
Disease control	N
Disease resistance management	N
Fertilization	N
Irrigation	N

Potato

Table 8 gives an overview of the most likely cultivation changes after the introduction of GM potato varieties containing late blight resistance or free from amylose.

The most likely traits to be introduced into commercial potato cultivation in the Maritime zone are an output trait, namely a change in starch composition from a mixture of amylose and amylopectin to an amylose free potato, and a disease resistance, against late blight. The amylose-free trait is an output trait with little likelihood of changes in cultivation practices.

A successful introduction of late blight resistant potato will potentially reduce fungicide applications up to 75%. However, the reduced application of fungicides may be accompanied by the increased development of secondary pests, and reduction of fungicides may be lower in reality. Because the same elite varieties as are presently cultivated form the base of the cisgenic late blight resistant lines, no other crop cultivation changes are expected.

Table 8. overview of the most likely cultivation changes after the introduction of GM potato varieties containing late blight resistance or that are amylose free.

	GM Potato varieties containing:	
Likely to change:	Late blight resistance	no amylose
Soil tillage	N	N
Herbicide use	N	N
Weed control	N	N
Insecticide use	N	N
Weed resistance management	N	N
Insect resistance management	N	N
Disease control	Y	N
Disease resistance management	Y	N
Fertilization	N	N
Irrigation	N	N

Farmers in the Maritime zone are also likely to choose methods that they perceive as being easier, simpler and cheaper. This implies that farmers who adopt HR crops are likely to continuously use herbicides with the same mode of action in the Maritime zone as well. This will lead to the development of herbicide resistant weeds at a faster rate than prior to the introduction of HR crops. The introduction of HR crops therefore calls for a well thought through resistance management scheme.

In areas in Europe's Maritime zone where specific insects cause a lot of damage, the IR crops could be adopted and insecticide use could decrease significantly in these areas.

References

Benbrook, C., 2009
Impacts of genetically engineered crops on pesticide use in the United States: The first thirteen years. Critical Issue Report. The Organic Center, Boulder, p VI + 62

Bonny, S., 2011
Herbicide-tolerant transgenic soybean over 15 years of cultivation: pesticide use, weed resistance, and some economic issues. The case of the USA. Sustainability 3:1302-1322

Brink, L. van den, C.B. Bus, A.C. Franke, J.A.M. Groten, L.A.P. Lotz, R.D. Timmer & C.C.M. van de Wiel, 2010
Inventory of observed unexpected environmental effects of genetically modified crops. 79 p. CGM report 2010-08, PPO report no.3250165700

Brink, L. van den, C.B. Bus, J.A.M. Groten, L.A.P. Lotz, R.D. Timmer & C. van de Wiel, 2008
Gewas- en teeltbeschrijving van suikerbiet, maïs en aardappel in relatie tot verspreiding van genetisch materiaal, 52 p. Rapport PPO nr. 3250099300

Bus, C.B., C.D. van Loon & A. Veerman, 1996
Teelt van pootaardappelen. 151 p. Teelthandleiding nr. 72 PAGV

Brookes, G. & P. Barfoot, 2012
GM crops: global socio-economic and environmental impacts 1996-2010. PG Economics Ltd, Dorchester, UK, p 187

Castiglioni, P., D. Warner, R.J. Bensen, D.C. Anstrom, J. Harrison, M. Stoecker, M. Abad, G. Kumar, S. Salvador, R. D'Ordine, S. Navarro, S. Back, M. Fernandes, J. Targolli, S. Dasgupta, C. Bonin, M.H. Luethy & J.E. Heard, 2008
Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions. Plant Physiol 147:446-455

Colbach, N., H. Darmency & Y. Tricault, 2010
Identifying key life-traits for the dynamics and gene flow in a weedy crop relative: Sensitivity analysis of the GeneSys simulation model for weed beet (*Beta vulgaris* ssp. *vulgaris*). Ecological Modelling 221:225-237

Cooke, L.R., H.T.A.M. Schepers, A. Hermansen, R.A. Bain, N.J. Bradshaw, F. Ritchie, D.S. Shaw, A. Evenhuis, G.J.T. Kessel, J.G.N. Wander, B. Andersson, J.G. Hansen, A. Hannukkala, R. Nærstad & B.J. Nielsen, 2011
Epidemiology and integrated control of potato late blight in Europe. Potato Research 54:183-222

Dill, G.M., 2005
Glyphosate-resistant crops: history, status and future. Pest Management Science 61:219-224

Dillen, K., P.D. Mitchell, T. van Looy & E. Tollens, 2010
The western corn rootworm, a new threat to European agriculture: opportunities for biotechnology? Pest Management Science 66:956-966

Dorhout, D.L. & M.E. Rice, 2010
Intraguild competition and enhanced survival of western bean cutworm (Lepidoptera: Noctuidae) on transgenic Cry1Ab (MON810) *Bacillus thuringiensis* corn. Journal of Economic Entomology 103:54-62

Downes, S., T. Parker & R. Mahon, 2010
Incipient resistance of *Helicoverpa punctigera* to the Cry2Ab Bt toxin in Bollgard II® cotton. PLoS One 5

Duke, S.O., 2005
Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science 61:211-218

Duke, S.O. & S.B. Powles, 2009
Glyphosate-resistant crops and weeds: now and in the future. AgBioForum 12:346-357

Fernandez-Cornejo, J. & M. Caswell, 2006
The first decade of genetically engineered crops in the United States. United States Department of Agriculture, Economic Research Service, Electronic Report, p 30

Fernandez-Cornejo, J., C. Klotz-Ingram, R. Heimlich, M. Soule, W. McBride & S. Jans, 2003
Economic and environmental impacts of herbicide tolerant and insect resistant crops in the United States. In: Kalaitzandonakes N (ed) The economic and environmental impacts of agbiotech: a global perspective. Kluwer Academic/Plenum Publishers, New York

Fernandez-Cornejo, J., R. Nehring, E. Newcomb Sinha, A. Grube & A. Vialou, 2009
Assessing recent trends in pesticide use in U.S. agriculture. Selected Paper Presented at the 2009 Meetings of the AAEA, Milwaukee, Wisconsin
Frisvold, G.B., A. Boor & J.M. Reeves, 2009
Simultaneous diffusion of herbicide resistant cotton and conservation tillage. (Special Issue: Herbicide resistant crops - diffusion, benefits, pricing, and resistance management.). AgBioForum 12:249-257
Gassmann, A.J., J.L. Petzold-Maxwell, R.S. Keweshan & M.W. Dunbar, 2011
Field-evolved resistance to Bt maize by western corn rootworm. PLoS ONE 6:e22629
Gómez-Barbero, M., J. Berbel & E. Rodríguez-Cerezo, 2008
Bt corn in Spain - the performance of the EU's first GM crop. Nature Biotechnology 26:384-386
Graef, F., G. Schütte, B. Winkel, H. Teichmann & M. Mertens, 2010
Scale implications for environmental risk assessment and monitoring of the cultivation of genetically modified herbicide-resistant sugar beet: a review. Living Reviews in Landscape Research 4
Haverkort, A.J., P.M. Boonekamp, R. Hutten, E. Jacobsen, L.A.P. Lotz, G.J.T. Kessel, R.G.F. Visser & E.A.G. v.d. Vossen, 2008
Societal costs of late blight in potato and prospects of durable resistance through cisgenic modification. Potato Research 51:47-57
Haverkort, A.J., P.C. Struik, R.G.F. Visser & E. Jacobsen, 2009
Applied biotechnology to combat late blight in potato caused by *Phytophthora infestans*. Potato Research 52:249-264
Heap, I., 2012
The international survey of herbicide resistant weeds. Available online: www.weedscience.com. Accessed June 2012.
Hutchison, W.D., E.C. Burkness, P.D. Mitchell, R.D. Moon, T.W. Leslie, S.J. Fleischer, M. Abrahamson, K.L. Hamilton, K.L. Steffey, M.E. Gray, R.L. Hellmich, L.V. Kaster, T.E. Hunt, R.J. Wright, K. Pecinovsky, T.L. Rabaey, B.R. Flood & E.S. Raun, 2010
Areawide suppression of European corn borer with Bt maize reaps savings to non-Bt maize growers. Science 330:222-225
Hutchison, W.D., T.E. Hunt, G.L. Hein, K.L. Steffey, C.D. Pilcher & M.E. Rice, 2011
Genetically engineered Bt corn and range expansion of the Western Bean Cutworm (Lepidoptera: Noctuidae) in the United States: A response to Greenpeace Germany. Journal of Integrated Pest Management 2:B1-B8
James, C., 2010
Global status of commercialized Biotech/GM crops: 2010 (ISAAA Brief 42). Ithaca, NY: International service for the Acquisition of Agri-biotech Applications (ISAAA)
James, C., 2011
Executive summary of 'Global status of commercialized biotech/GM crops: 2011'. ISAAA Brief No 43. ISAAA, Ithaca, NY, p 11
Jost, P., D. Shurley, S. Culpepper, P. Roberts, R. Nichols, J. Reeves & S. Anthony, 2008
Economic comparison of transgenic and nontransgenic cotton production systems in Georgia. Agronomy Journal 100:42-51
Kalaitzandonakes, N.P.S., 2003
Adoption of cotton biotechnology in the United States: Implications for impact assessment. In: Kalaitzandonakes N (ed) The economic and environmental impacts of agbiotech: a global perspective. Kluwer Academic/Plenum Publishers, New York, pp 103–118
Kaniewski, W.K. & P.E. Thomas, 2004
The potato story. AgBioForum 7:41-46
Kempenaar, C., L. v.d. Brink, C.B. Bus, J.A.M. Groten, C.L.M. de Visser & L.A.P. Lotz, 2003
Gangbare landbouwkundige praktijken en recente ontwikkelingen voor vier akkerbouwgewassen in Nederland. Plant Research International, Wageningen, p 37 (in Dutch)
Khan, M.F.R., 2010
Introduction of glyphosate-tolerant sugar beet in the United States. Outlooks on Pest Management 21:38-41
Kocmánková, E., M. Trnka, J. Eitzinger, M. Dubrovský, P. Štěpánek, D. Semerádová, J. Balek, P. Skalák, A. Farda, J. Juroch & Z. Žalud, 2011

Estimating the impact of climate change on the occurrence of selected pests at a high spatial resolution: a novel approach. Journal of Agricultural Science 149:185-195

Kroonen-Backbier, B., 2011
Werken aan schoner oppervlaktewater in intensieve maïsteelt gebieden. Pilotstudie maïscasus in de Hoge en Lage Raam in 2008, 2009 en 2010. WUR-PPO AGV, http://edepot.wur.nl/167517

Loon, C.D. van, A. Veerman & C.B. Bus, 1993
Teelt van Consumptiie-aardappelen 142 p. Teelthandleiding nr. 57 PAGV

Lu, Y.H., K.M. Wu, Y.Y. Jiang, B. Xia, P. Li, H.Q. Feng, K.A.G. Wyckhuys & Y.Y. Guo, 2010
Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. Science 328:1151-1154

May, M.J., 2003
Economic consequences for UK farmers of growing GM herbicide tolerant sugar beet. Annals of applied biology 142:41-48.

McGinnis, E.E., M.H. Meyer & A.G. Smith, 2010
Sweet and sour: a scientific and legal look at herbicide-tolerant sugar beet. Plant Cell 22:1653-1657

McHale, L., X.P. Tan, P. Koehl & R.W. Michelmore, 2006
Plant NBS-LRR proteins: adaptable guards. Genome Biology 7:212

Mensah, E.C., 2007
Factors that affect the adoption of Roundup Ready soybean technology in the U.S. Journal of Economic Development and Business Policy 1:90-121

Mills, C.I., C.W. Bednarz, G.L. Ritchie & J.R. Whitaker, 2008
Yield, quality, and fruit distribution in Bollgard/Roundup Ready and Bollgard II/Roundup Ready Flex cottons. Agronomy Journal 100:35-41

Mortensen, D.A., L. Bastiaans & M. Sattin, 2000)
The role of ecology in the development of weed management systems: an outlook. Weed Research 40:49-62

Mortensen, D.A., J.F. Egan, B.D. Maxwell, M.R. Ryan & R.G. Smith, 2012
Navigating a critical juncture for sustainable weed management. BioScience 62:75-84

Mulugeta, D. & C.M. Boerboom, 2000
Critical time of weed removal in glyphosate-resistant *Glycine max*. Weed Science 48:35-42

National Research Council, Committee on the impact of genetically engineered crops on farm sustainability in the United States, 2010
The impact of genetically engineered crops on farm sustainability in the United States. The National Academies Press, Washington DC

Nesbitt, T.C., 2005
GE foods in the market. (ed. CUC Extension), Ithaca, NY.

Owen, M.D.K., 2008
Weed species shifts in glyphosate-resistant crops. Pest Management Science 64:377-387

Park, T.H., V.G.A.A. Vleeshouwers, E. Jacobsen, E. van der Vossen & R.G.F. Visser, 2009
Molecular breeding for resistance to *Phytophthora infestans* (Mont.) de Bary in potato (*Solanum tuberosum* L.): a perspective of cisgenesis. Plant Breed 128:109-117

Roberts, R.K., B.C. English, Q. Gao & J.A. Larson, 2006
Simultaneous adoption of herbicide-resistant and conservation-tillage cotton technologies. Journal of Agricultural and Applied Economics 38:629-643

Schütte, G. & M. Mertens, 2010
Potential effects of the introduction of a sugar beet variety resistant to glyphosate on agricultural practice and on the environment. BfN-Skripten (Bundesamt für Naturschutz). Bundesamt für Naturschutz (German Federal Agency for Nature Conservation), Bonn, p 58

Shelton, A.M., J.Z. Zhao & R.T. Roush, 2002
ECONOMIC, ecological, food safety, and social consequences of the development of Bt transgenic plants. Annual Reviews of Entomology 47:845–81

Stachler, J.M., A.L. Carlson, M.F.R. Khan & M.A. Boetel, 2011
Survey of weed control and production practices on sugar beet in Minnesota and Eastern North Dakota in 2011 (North Dakota State University, Fargo.

Tabashnik, B.E., M.S. Sisterson, P.C. Ellsworth, T.J. Dennehy, L. Antilla, L. Liesner, M. Whitlow, R.T. Staten, J.A. Fabrick, G.C. Unnithan, A.J. Yelich, C. Ellers-Kirk, V.S. Harpold, X.C. Li & Y. Carrière, 2010 Suppressing resistance to Bt cotton with sterile insect releases. Nature Biotechnology 28:1304-1307

Tabashnik, B.E., J.B.J. van Rensburg & Y. Carrière, 2009
Field-evolved insect resistance to *Bt* crops: definition, theory, and data. Journal of Economic Entomology 102:2011-2025

Tripp, R., 2009
Biotechnology and agricultural development : transgenic cotton, rural institutions and resource-poor farmers. Routledge, London

Van de Wiel, C.C.M. & L.A.P. Lotz, 2006
Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: a case study of the situation in the Netherlands. NJAS Wageningen Journal of Life Sciences 54:17-35

Veerman, A., R. Wustman, C.B. Bus, K.H. Wijnholds, 2006
Zetmeelaardappelen Teelthandleiding PPO325 p.151

Visser, R.G.F., I. Somhorst, G.J. Kuipers, N.J. Ruys, W.J. Feenstra & E. Jacobsen, 1991
Inhibition of the expression of the gene for granule-bound starch synthase in potato by antisense constructs. Molecular and General Genetics 225:289-296

Weed Science Society of America, 1998
'Herbicide resistance' and 'herbicide tolerance' defined. Weed technology 12 (4): 789

Zhu, S., Y. Li, J.H. Vossen, R.G.F. Visser & E. Jacobsen, 2012
Functional stacking of three resistance genes against *Phytophthora infestans* in potato. Transgenic Research 21:89-99