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Project Number 289706

COLLABORATIVE PROJECT

Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems

D10.2 **Economic model capable of estimating revenue implications of adopting transgenic crops in the EU.**

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Dissemination Level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Background and Objectives

This deliverable relates to the construction of an economic model capable of estimating the revenue implications of adopting (and not adopting) a variety of transgenic crops within the EU. It has been constructed to align with the five EU regions that are the focus of the AMIGA project. As noted in the DOW the work to date on this deliverable has focussed on the construction of a working model. The full use and outputs from the model will be derived during the period of the project as more data becomes available, the final output being in the form of a Journal paper (as outlined in deliverable 10.7.)

The objectives of this paper are:

- To provide a brief review of available models
- To outline the overall principles adopted in the model construction process
- To describe the model parameters
- To communicate the assumptions made in construction
- To provide evidence of model calibration and validation
- To demonstrate initial use with preliminary scenarios.

2. Model review

Many previous studies have been published concerning the economic impact of transgenic crops and these were reviewed as part of deliverable 10.1. A few of these economic studies have been based on the formal representation of economic models. We note here some of the examples of relevant previous studies.

Broader policy models

Some of these models are broader based policy models, for example Anderson and Cavendish (2001) developed a dynamic simulation framework for exploring policy options, to assess the role of technical developments in relation to environment protection policy, permitting the introduction of time lags, and effects of changing preferences. Similarly, Munro (2003) estimated coefficients in expressions for consumer demand to arrive at conditions for competitive equilibrium, which required solving second-order equations for optimal pricing over two time periods. Some conclusions were reached regarding regulations that pertain to development and deployment of new transgenic varieties. Household surveys have also provided data for a different approach; for instance, Vitale et al (2007) and Vitale et al (2010) used survey data to estimate coefficients in sets of difference equations, and thus quantify the economic viability of Bt cotton for small-scale farmers in Mali and Burkina Faso, both under severe pest pressure.

In the context of developing countries, Raney (2006) reviewed factors that influence the level and distribution of the economic value created by transgenic crops using *ex-post* studies of herbicide-tolerant (HT) and insect-resistant (IR) maize grown in Argentina and South Africa.

In the research project “Sustainable Introduction of GMOs into European Agriculture” (SIGMEA) funded by the Sixth Framework Programme of the EC, Gómez-Barbero and Rodríguez-Cerezo (2006) estimated the global economic welfare generated by adoption of four dominant transgenic crops:

- Herbicide Tolerant soybean
- Insect-Resistant cotton

- Insect-Resistant maize
- Herbicide Tolerant rapeseed/canola.

It was concluded that [at that time] on-farm benefits were derived from reducing production costs. For some crops there were also yield increases (particularly in the case of Bt cotton). Adoption of HT soybean in the US had no significant effect on on-farm income, but resulted in crop management simplification, increased free time, and larger off-farm incomes for adopting farmers resulting in net benefits for adopters. The net economic benefits for farmers were variable in regional terms: the crops were designed to solve pest and weed problems which vary greatly in their geographical distribution. Small farmers had shown no difficulty in adopting the technology and adoption rates were not related to farm size. Moreover, detailed analyses (for example of Bt cotton in China) showed that increases in gross margin were comparatively larger for smaller and lower income farmers than for larger and higher income farmers. Of the four crops:

- adoption of HT soybean had resulted in displacement of several herbicides by a single less toxic product
- Bt cotton adoption had resulted in a significant decrease in the use of insecticides
- Bt maize adoption had induced only a little decrease in insecticide
- HT canola was grown exclusively in Canada and the USA; net aggregate benefit for farmers in the year 2000 was estimated to be about €12 per hectare.

More specific crop based models

Bachinger and Zander (2007) described a rule-based model in which a set of annual crop production activities was assembled from crop-specific field operations using a relational database, allowing for all possible 3 to 8 year crop rotation sequences within the constraints of organic farming, to optimise weed and site-specific N management. Gross margins were calculated from estimated yields, including the effects of crop subsidies. A feature of the model was sensitivity to soil quality as well as to preceding crop effects. The tool was able to generate and select agronomically sustainable crop rotations specific to the conditions of organic farming.

In relation to Bt varieties and pesticide-based control strategies of cotton–bollworm, Pemsl et al (2008) developed a bio-economic model which included the simulation of plant growth and of the dynamics of pest populations and of natural enemies. The model was used to explain the observed decision-making behaviour of farmers in northern China, who had opted for the cheaper and lower quality Bt seeds, and continued to spray insecticides against the cotton–bollworm. Model results showed the importance of the interaction between ecosystem disruption and pest control strategies. Indiscriminate insecticide use had a stronger side effect on beneficial insects than adoption of Bt cotton.

Spatial effects of the introduction of transgenic crops were modelled by Munro (2008), who noted that co-existence with conventional crops is associated with strong regulation on planting patterns. In a review of economic impacts of transgenic herbicide-resistant crops, Gianessi (2008) included reductions in herbicide expenses, increases in seed costs, increased yield and changes in the relative profitability of crops that has resulted in changes in choice of crops to be planted, and in addition, non-pecuniary benefits accrued as a result of the simplicity of weed management in the glyphosate-resistant crop systems.

Cui et al (2009) used the term ‘system dynamics’ for simulation technology based on feedback control theory, and applied the method to investigate yield, resource utilisation and soil fertility and thus estimate economic outcomes, all with reference to paddy field crop rotations. They reported simulation of a ‘three-level orthogonal experiment’, validated in tests in the Chengdu plain region of China in 1998. They noted from their work that the development of three crops per year in paddy fields may improve long-term sustainability of paddy field ecosystems.

In trying to estimate the impacts of future events, Johnson et al (2008) constructed a quantitative model of the US wheat sector to analyse the potential economic impact of commercializing HT wheat. The model included two classes of wheat, including both biotech and non-biotech varieties. They used an assumed elasticity of substitution and an overall elasticity of wheat demand, with demand apportioned to market shares.

European context

Anderson (2010) reported results of a GTAP-based spreadsheet simulation of adoption of a range of GM crops that might have occurred had the EU moratorium not been in place, concluding that gains to developing countries from GM crops will be only slightly lower if EU policy continues to restrict imports. More recently, using a simple partial budgeting approach, Park et al (2011) estimated the revenue foregone by denying EU farmers the opportunity of cultivating these crops to be in the range €443 to €929M per year, based on performance achieved with these crops in other parts of the world.

An alternative way to model farm-level crop rotation was described by Schonhart et al (2011), who first reviewed diverse frameworks for modelling land use. They noted that economic representations are increasingly ‘bottom up’ to account for environmental and production costs as well as crop sequence management, commenting that land use modelling at regional level is ‘coarse at best’. They give details, including coding, of a linear programming model written in the GAMS software package, which permits aggregation from farm to region, and from single to multiple years. The model was validated using seven years of data from 579 arable farms in Austria, and sensitivity analysis on model parameters was performed with random (Monte Carlo) variations.

Bohanec et al (2008) reported on use of a qualitative multi-attribute using a system known as DEXi, described as the largest and most integrative model developed within the ECOGEN (EC Framework 5, Scatasta et al, 2006) and SIGMEA projects. The system integrated findings of different specific disciplines, such as agronomy, biology, ecology and economics, and provided a general overview of cropping systems defined by four groups of features: (1) crop sub-type, (2) regional and farm-level context, (3) crop protection and crop management strategies, and (4) expected characteristics of the harvest. The model was considered useful for what-if analysis of realistic cropping systems.

A number of broader crop-based models have been funded by the EU. The System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS, van Ittersum M. et al, 2008) modelling framework was investigated in some detail to establish whether it could form the basis for this modelling exercise. The software infrastructure of the project was anticipated to provide an open source means to facilitate linkage and integration of models and other knowledge sources from different domains and programmed in different environments and languages. After reviews of papers emanating from this project (Alkan Olsson J., et al, 2009; Ewert F., et al, 2009; Therond O., et al, 2009; Donatelli M., et al, 2010) and discussions with the overall project co-ordinator the WP10 team decided that the economic components of SEAMLESS would require a complete reconfiguration to meet the objects of the AMIGA project. On the basis of the above review and more in depth consideration of existing modelling frameworks it was concluded that the best approach to achieve the objectives of work package 10 was to construct a new model, drawing on elements of previous work where possible. The basis of the "**M**odel of **E**conomic consequences of **T**ransgenic crops in the **E**U" (METE) is described in the following sections.

3. Outline of model principles and construction

Given the fact that economic performance of any crop is affected by soil condition following harvest of the preceding crop and by treatments applied during crop development, we evaluated alternative software platforms that accommodate dynamic multivariable modelling combined with ease of performing sensitivity analysis on model predictions. Given also the need for the model to accommodate in due course input from experiments undertaken by partners in the AMIGA consortium, modelling software is required that not only allows dynamic model behaviour but will also readily accommodate the incorporation of those inputs. We have some previous experience of dynamic simulation modelling with STELLA (www.iseesystems.com/softwares/Education/StellaSoftware.aspx) and with Berkeley MADONNA (www.berkeleymadonna.com) which have similar features that facilitate development in a highly structured framework. The General Algebraic Modelling System (GAMS), used for example by Schonhart et al (2011) to model crop rotation, also offers all the features that may be needed; it is fully portable between PC operating systems and is freely available.

However, initial investigations of the above suggested that the type of versatility required within the METE model meant that a direct programming approach was probably the best approach to meet the functionality required with the model. Unlike STELLA and MADONNA, MS Visual Basic (VB) enables easily the use of stochastic perturbation of variables, which we deemed to be of particular use in the METE model where accurate estimates of some of the parameters will be difficult to obtain. VB is also seamlessly compatible with MS Excel and MS Word which is very useful in terms of inputing variables and deriving results.On that basis the METE model was constructed in VB, which has very flexible user interface options. The WP10 team have previous experience of using VB for the construction of a model to demonstrate economic outcomes of proposed methods for dealing with wildlife transmission in strategies to limit farm losses from bovine TB (see Wilkinson et al, 2009), thus had confidence in potentially functionality allowed via the use of VB.

3.1 Model specification

Time period. Crop rotations typically extend over two to five years; the model accommodates scenarios of crop sequences adopted over a five year period. This enables the effects of crop and crop management choices on subsequent crops to be modelled. It is also possible to model a single growth year.

Time step. As the model is an economic model as opposed to a model of crop development, we consider that one month time steps are sufficient to model the management decisions that may be made during a crop cycle.

Area to be modelled. Coexistence costs are partly set by the need to provide separation from conventional crops on adjacent land, and so the cost will vary with the area occupied by a transgenic crop. The model allows for simulations with a range of field sizes. For instance the model allows the user to specify average field sizes between 4 and 80 ha.

Five regions. The AMIGA proposal FP7-KBBE-2011-5-CP-CSA specifies that assessment is to be based on five biogeographic regions: 'Participants to the AMIGA project will constitute 5 regional groups: Atlantic (Ireland, UK, Denmark, Netherlands), Boreal (Finland, Sweden), Continental (Austria, Germany, Slovakia), Mediterranean (France, Italy, Spain), and Balkans (Bulgaria, Romania). The [first four] areas were selected similarly to [those] indicated in the Natura 2000 approach (Boreal, Atlantic, Continental, Mediterranean). In addition we indicated a fifth area (Balkans), which includes two countries that according to Natura 2000 belong to four different zones.'

Choice of sets of crops. The model allows the selection of conventional crops and crop sequences which are common in a given biogeographic region. Where available the GM alternative can be selected.

Physical and economic parameters. A table of typical yield per hectare of the selected crops, together with seed costs and ex-farm value per tonne at harvest was compiled using published data. Further costs taken into account are the costs of tillage, pesticides and herbicides, together with, for some regions and crops, the cost of irrigation.

Model outcomes. The model computes the predicted variations in yield of each crop in a five year sequence of monocropping or crop rotation. Many possible crop sequences can be assessed for an arable farm of a specific size in any one of the five regions of the EU identified in the AMIGA project.

Calculations. Simulation proceeds in up to 60 monthly steps, with crop potential yield re-estimated each month that the crop is in the soil, in response to simulated levels of pressure associated with pests, weeds and drought. The simulated pest and drought pressures each have a stochastic component. Potential yield variation in response to the various pressures is calculated using coefficients obtained from published data.

Management strategies. The user interface allows for the opportunity to compare the consequences of management decisions regarding extent of tillage and applications of pesticide and herbicide, and use of irrigation where relevant.

User interface. The calculations are performed in MS Visual Basic for Applications (VBA), each sequence being initiated from a VBA User Form (Figure 1) that allows choice of EU region, farm size and initial pressure in three categories (pest, weed and drought), and choice of crops in the rotation from drop-down lists of available crop options.

Results. Economic outcomes are presented primarily as gross margin for each crop in the rotation, together with the sum of the margins for each of the crops in the 5 year sequence. The outcomes are tabulated in MS Excel worksheets, and the user can inspect these before deciding whether, via the User Form, to discard them or transfer the worksheets for saving in a separate newly-created MS Excel workbook. Combined outputs can be quickly graphed to so that multiple outputs can be displayed.

4. Model parameters

The 24 crop options from which rotations can be compiled are listed in each of Tables 1, 2 and 3, where the agronomic variables associated with each crop (obtained from published data) are listed.

Table 1 contains:

- growing period (in months) required for each crop
- potential yield per hectare
- seed cost per hectare
- crop value at harvest, per tonne
- cost of minimum and full tillage
- cost per application of pesticide and herbicide
- cost per hectare of irrigation (where used)

Table 2 contains:

- rate of impairment of yield due to pests
- rate of impairment due to weeds
- vulnerability to drought

Table 3 contains:

- normal extent of tillage
- typical number of pesticide applications
- typical number of herbicide applications
- irrigation policy.

Comparison can readily be made between crop scenarios, and the model has three modes of operation:

- to assess the performance of a single crop over one growing cycle
- to assess the performance of the same crop over five consecutive cycles (for instance continuous maize growing, either conventional or transgenic)
- to assess the combined performance of a set of crops in rotation over five growing cycles (for instance up to 5 different crops, one or more of which may be a GM variety).

In every case, crops are subject to varying levels of pest, weed and drought pressure. There is an option to simulate the performance of the crop including the absence of any of these pressures, which enables a direct prediction to be made of the economic impact of a specified level of each type of pressure.

5. Model assumptions

[Coding of the assumptions is given in Appendix B].

Yield of each crop in a sequence is initially assumed to be as in published data for that crop for typical farms in that region.

The potential yield is recalculated for each month that the crop is in the soil as an empirical function of:

- typical growth pattern for that crop
- pest pressure, taking account of past management policy and prior conditions
- weed pressure, taking account of tillage and weed management policy, and prior conditions
- Water use management, taking account of simulated drought pressure
- GMO traits.

The rate at which potential yield is reduced under pest pressure is calculated using a coefficient for each crop, using published data if available, or by inference from observed effect on other crops if necessary. Pests, where present, exert stochastically variable and gradually increasing pressure unless managed via pesticide application. In each month in which simulated pest pressure reaches a specified level, broad spectrum pesticide is applied if that is the management policy selected. If the crop is changed as in a normal rotation, pest pressure is reduced with change of host crop. If the crop is IR, it is assumed that the pest population is reduced. This lessens the extent to which pest pressure impairs potential yield of the crop. The reduction in pest population also results in reduced pest pressure for a subsequent crop.

The rate at which potential yield is reduced under weed pressure is calculated using a coefficient for each crop, using published data if available, or by inference from observed effect on other crops if necessary. Weeds, once established, exert progressively increasing pressure unless managed. In each month in which simulated weed pressure reaches a specified level, broad spectrum herbicide is applied if that is the management policy selected. If the crop is HT, it is assumed that glyphosate or similar herbicide is applied while the crop is in the ground, and that weed pressure and therefore the impact of weeds on potential yield is reduced. This alleviation of weed pressure is assumed to reduce weed pressure for a subsequent crop.

The effect of drought pressure is calculated using a coefficient for each crop, using published data if available, or by inference from observed effect on other crops. Legume crops are assumed to have a beneficial effect on the performance of the subsequent crop in relation to residual fertility. This benefit has been estimated from the literature.

Impairment of potential yield due to multiple simultaneous pressures is assumed to be somewhat less than would have been imposed by the sum of those pressures acting separately (i.e. a crop already affected by a strong pressure is only partially further impaired by other unrelated pressures).

6. Validation and sensitivity analysis

Initial testing and commissioning of the model has been performed, in three stages:

- Simulation of one growing cycle of maize, recording the progress each month under progressively severe pest pressure, comparing Bt maize with conventional maize
- Extending the simulation to five cycles of continuous cultivation of either Bt or conventional maize
- Simulation of a five year rotation of crops under progressively severe weed pressure, comparing results from replacing one cycle of conventional sugarbeet with HT sugarbeet.

Model parameters have been adjusted to ensure that model outcomes are consistent with *ex-post* published data of reports of the performance of IR and HT crops, particularly reports of the Bt maize grown in Spain.

The outcomes for the model runs for Bt maize, both as a single crop and as a continuous crop, are consistent with the findings of Gómez-Barbero, Berbel and Rodriguez-Cerezo (2008), who used data from an *ad hoc* survey of maize farmers in Spain to assess the factors that might have affected Spanish farmers' decisions whether or not to adopt Bt maize technology, and to calculate the differences in agronomic and economic performance between adopters and non-adopters.

HT sugarbeet is a crop likely to be of great interest to European farmers; Dillen et al (2013) published data on the performance of HT sugarbeet following widespread adoption in USA and Canada. Our third set of tests used the scenario wherein one cycle of sugarbeet is included in a five year crop rotation in AMIGA Region 4 (Denmark, Netherlands, Ireland, Belgium, Luxembourg, Portugal, UK), with results consistent with the data of Dillen et al for similar cultivation in North America.

6.1 Input data sets

Data for parameters associated with a set of crops (initially 16 conventional and 7 GMO crops, with a further ‘fallow’ option), are tabulated in a set of spreadsheets addressable in the model coding Tables 1, 2and 3. Results of simulations are assembled in further data sheets, which are then copied as required to new Excel Workbooks created within the program, and named accordingly. Selections of significant results are presented in graphical format during subsequent reporting.

Access to the model is via a single UserForm (Figure 1), on which there are tabs to select one of three versions of simulation:

- A single cultivation with options as depicted (Figure 1a)
- Cultivation of one crop for 5 consecutive years (Figure 1b)
- Cultivation of crops in a 5 year crop rotation (Figure 1c).

In each version, the crop or crops can be selected from a menu populated with the same set of crops, the region can be selected from the five EU regions as defined for the AMIGA project, and plot size can be between 4 and 80 ha. Initial levels of pressure from pests, weeds and drought can be specified, and these then vary during the steps of the simulation as determined by the simulated environment and in accordance with preset management scenarios.

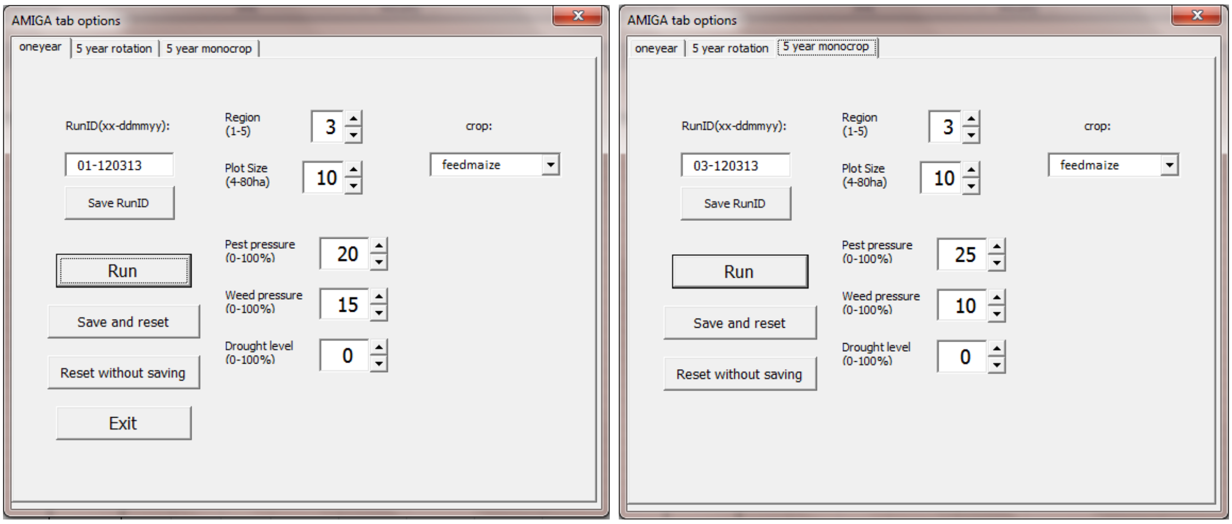


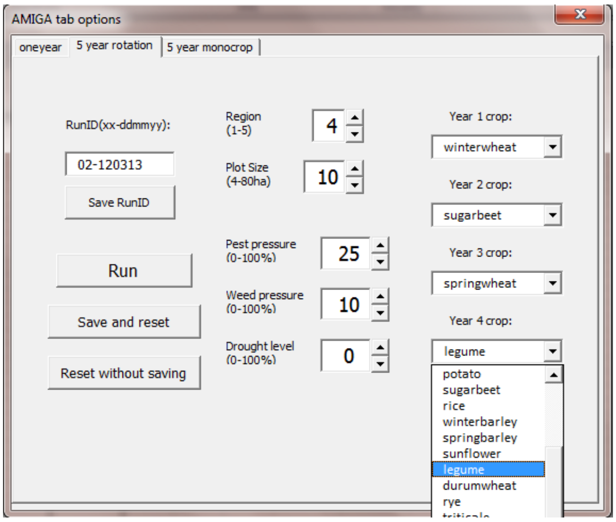
Figure 1 – The User Form

1a – Single year

1b – Five year monocrop

1a:
RunID(xx-ddmmyy): 01-120313
Region (1-5): 3
Plot Size (4-80ha): 10
crop: feedmaize
Pest pressure (0-100%): 20
Weed pressure (0-100%): 15
Drought level (0-100%): 0

1b:
RunID(xx-ddmmyy): 03-120313
Region (1-5): 3
Plot Size (4-80ha): 10
crop: feedmaize
Pest pressure (0-100%): 25
Weed pressure (0-100%): 10
Drought level (0-100%): 0



1c – Five year rotation

RunID(xx-ddmmyy): 02-120313
Region (1-5): 4
Plot Size (4-80ha): 10
Pest pressure (0-100%): 25
Weed pressure (0-100%): 10
Drought level (0-100%): 0
Year 1 crop: winterwheat
Year 2 crop: sugarbeet
Year 3 crop: springwheat
Year 4 crop: legume

Pressures are combined using an empirical relation, and the potential yield of each crop is recalculated at each monthly step until the month of harvest. At that point, the predicted value of the crop is calculated on the basis of a preset price per ton for that crop, and the farmer's gross margin found by subtracting the cost of seed, control measures and (if the crop is GMO) the costs of coexistence.

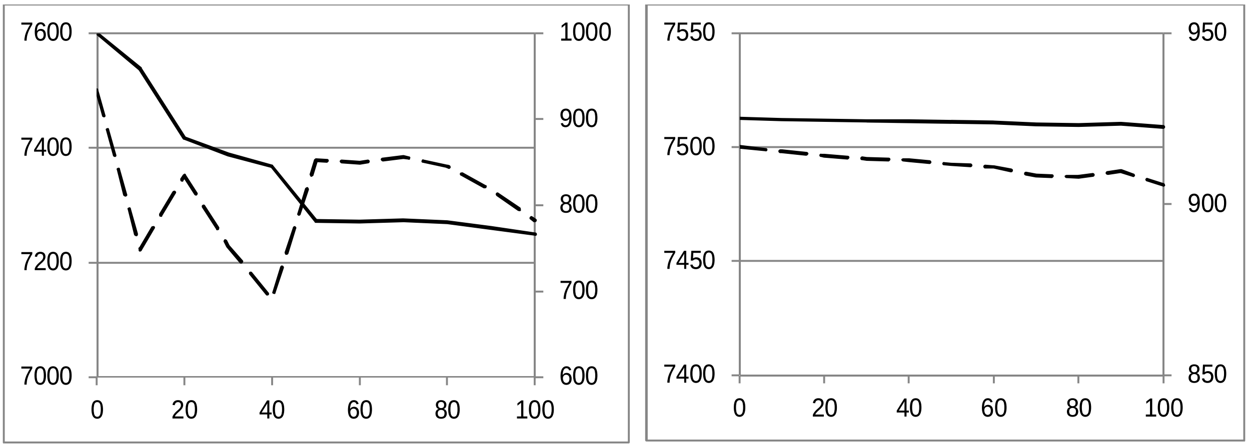
6.2 Sample outcomes

Typical outcomes from each version of the model are illustrated graphically in Figures 2-4.

Figure 2 shows the effect of increase in pest pressure (horizontal axis) on yield (left vertical axis) and gross margin (right vertical axis) per hectare for conventional maize (Figure 2a) and insect-resistant Bt maize (Figure 2b). With conventional feedmaize, the farmer is assumed to make one application of pesticide when pests appear, and a second application when pressure exceeds 50%. The gross margin for Bt maize in the absence of pests is less than the gross margin for conventional maize, but the margin for Bt maize is maintained at all pressures when pests are present in the locality.

Figure 2 – Single cultivation of maize
(horizontasl axis: combined pressure as % of maximum)

2a (conventional) 2b (Bt maize)

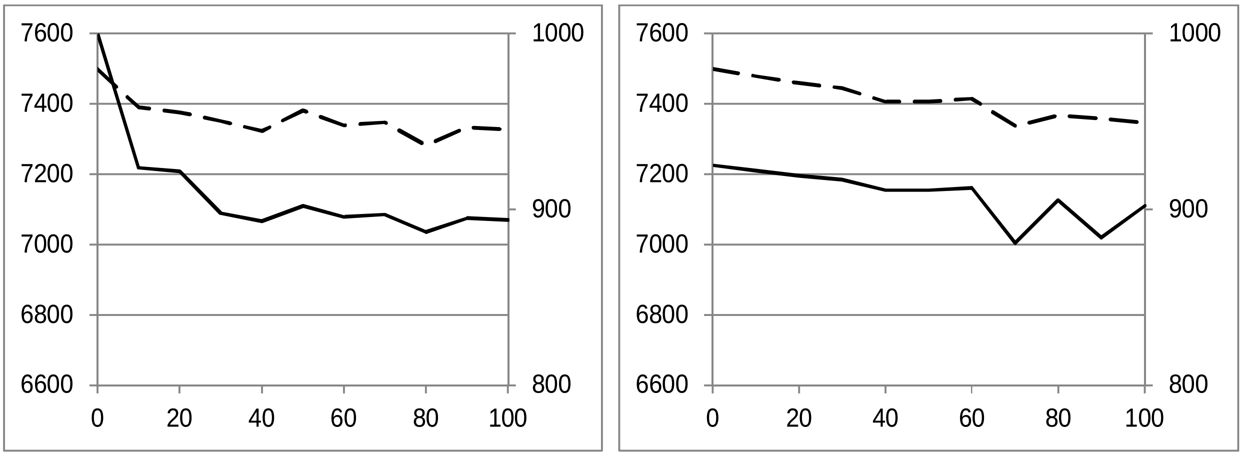


Left scale: kg/ha (dashed line) — — — Right scale: €/ha (solid line) ———

Figure 3 shows the average yield and average gross margin for five years of continuous cultivation of either conventional maize (Figure 3a) or Bt maize (Figure 3b), with average pest pressure on the horizontal axis. With five years of continuous maize, the yield of Bt maize is maintained, and the average gross margin preserved, up to the severity of pest prerssure at about 70%. At this point the prolonged severe pest pressure requires intervention in the form of additional conventional persticide applications.

Figure 3 – Five years of continuous maize
(horizontasl axis: combined pressure as % of maximum)

3a – conventional maize 3b – Bt maize



Left scale: kg/ha (dashed line) — — — Right scale: €/ha (solid line) ———

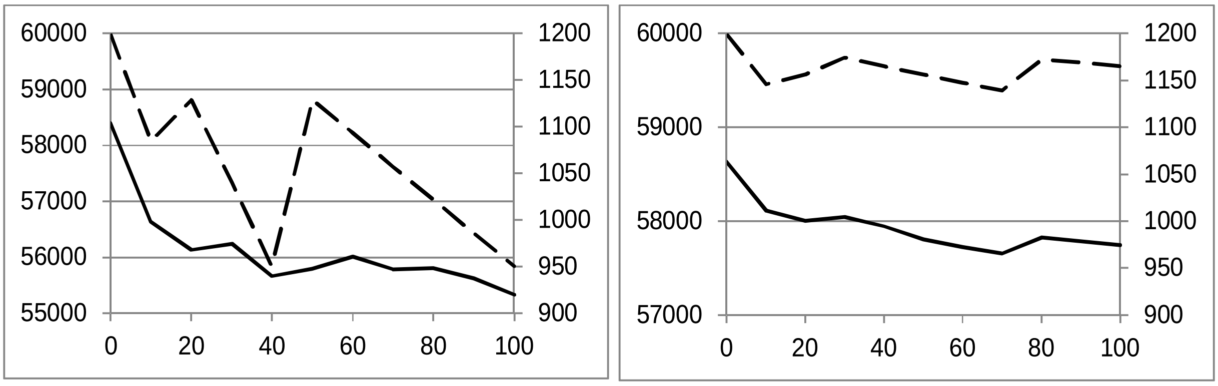
Figure 4 shows part of the outcome of a five-year crop rotation, with either conventional or herbicide tolerant sugarbeet grown in the second year, a legume grown in fourth year, and wheat grown in the first, third and fifth years. The horizontal axis represents weed pressure at commencement of the rotation, and on the vertical axis is shown:

- Beet yield per hectare (left scale)
- Average gross margin per hectare for all five years (right scale)

The outcome suggests that adopting HT sugarbeet for one year is beneficial to the overall outcome in all scenarios except that of complete absence of weeds.

Figure 4 – Five years, sugarbeet in year 2 of a 5 year rotation
(horizontasl axis: combined pressure as % of maximum)

4a – conventional beet 4b – HT beet



Left scale: beet kg/ha (dashed line) — — — Right scale: average €/ha (solid line) ———

7. Discussion and conclusions

As outlined above, the main focus of D10.2 has been the construction of a working model. This will be used and adapted throughout the duration of the AMIGA project as new scenarios for use become apparent and as new data becomes available. The main outputs from model use will form the basis for an academic paper or papers as per Deliverable 10.7. Here we have highlighted three potential future scenarios and the resultant model outputs.

In this report we have reviewed above a number of previous methods for modelling the agronomic and economic performance of transgenic crops, particularly those equivalent to conventional varieties grown extensively in countries in the EU. We have assessed the requirements for the modelling work specified within AMIGA WP10, and from the resources available we made the decision to construct a dynamic model in the MS Visual Basic for Applications (VBA) environment, which would allow us to integrate data as it becomes available throughout the project.

There is some suggestion that the on-going regulations which means that EU farmers either have no access or very limited access to GM varieties has deterred the major seed suppliers from developing GM alternatives to common arable crops agronomic issues in the EU (Moschini, 2008, Williams 2010, Laursen 2012). It is thus doubly difficult to model *ex-ante* the agronomic and economic performance of GM crops that might be cultivated here: to the difficulty of extrapolation from data on performance of GM crops elsewhere in the world must be added the uncertainty as to how well GM crops not yet adapted for European farming might perform.

This report outlines the design and testing of a model “Model of Economic consequences of Transgenic crops in the EU” (METE) that simulates in one month steps the effect on potential yield and gross margin of crops grown in a single cycle, continuously over several crop cycles, and as part of a crop rotation over five years, subject in each case to varying levels of pest, weed and drought pressures, with associated applications of pesticide, herbicide and irrigation.

The METE model takes account of costs of compliance with regulations concerning coexistence of transgenic and conventional crops: unlike elsewhere in the world, coexistence costs in Europe fall entirely on the transgenic crop grower.

Initial model validation runs suggest that the METE model is capable of simulating different crops and rotations across the EU. Validation runs suggest, not surprisingly, that any advantage of IR and HT crops is likely to be related to the pest and weed pressure in a given area. However, much more detailed model runs will be undertaken to investigate a range of potential scenarios, the outputs of which will be reported in academic papers (as per D10.7). Our conclusion is that the METE model provides a flexible framework to investigate a range of GM crop scenarios between now and the end of the project. The framework is such that it will allow the investigation of a range of scenarios across the five Amiga regions and can be updated as new data becomes available.

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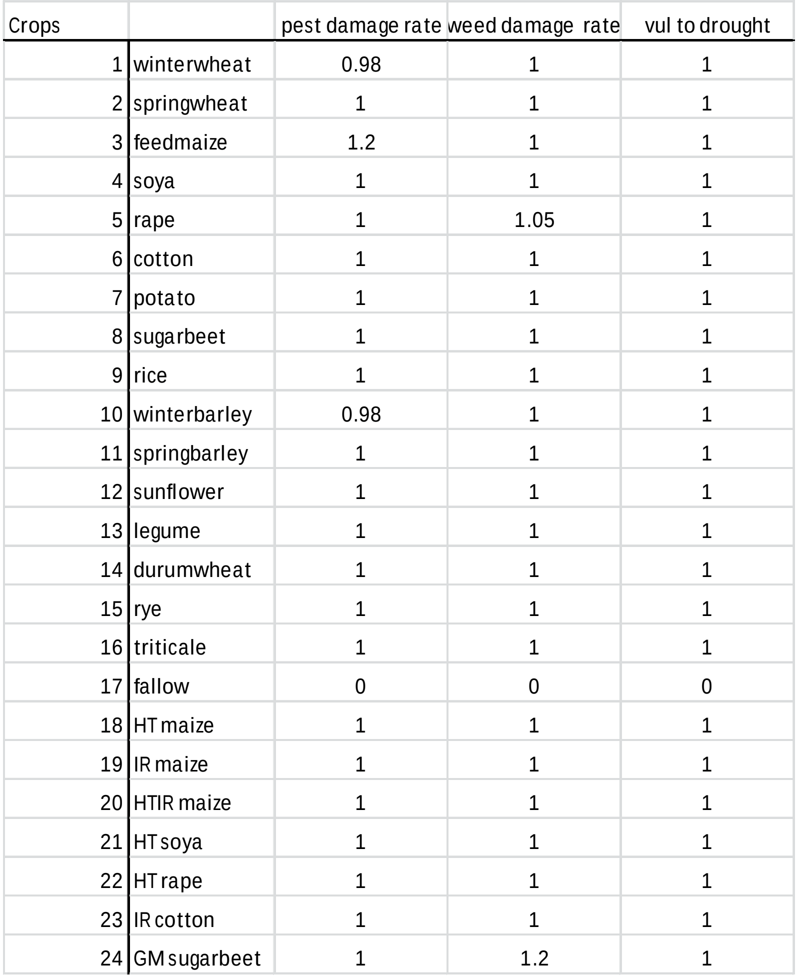
Tables

Table 1 – Economic parameters

Crops		drill-mth	end-mth	yield-kg/ha	seed-€/ha	harvest-€/t	min till-€/ha	tillage-€/ha	pesticide-€/ha	herbicide-€/ha	irrigation-€/ha
1	winterwheat	1	6	8000	60	150	50	120	100	100	200
2	springwheat	2	8	6000	60	150	50	120	100	100	200
3	feedmaize	2	8	7500	125	150	50	120	100	100	200
4	soya	3	9	3000	100	400	50	120	100	100	200
5	rape	3	9	3000	50	350	50	120	100	100	200
6	cotton	3	9	1500	200	2500	50	120	100	100	200
7	potato	2	7	40000	800	150	50	120	100	100	200
8	sugarbeet	2	7	60000	200	40	50	120	100	100	200
9	rice	2	8	8000	120	250	50	120	100	100	200
10	winterbarley	1	6	6300	78	164	50	120	100	100	200
11	springbarley	2	8	4950	80	196	50	120	100	100	200
12	sunflower	3	9	2160	108	390	50	120	100	100	200
13	legume	2	8	1400	109	220	50	120	100	100	200
14	durumwheat	2	8	5450	138	232	50	120	100	100	200
15	rye	2	8	4600	100	155	50	120	100	100	200
16	triticale	2	8	5440	70	138	50	120	100	100	200
17	fallow	1	12	0	0	0	0	0	0	0	0
18	HT maize	2	8	7500	150	150	50	120	100	80	200
19	IR maize	2	8	7500	150	150	50	120	100	100	200
20	HTIR maize	2	8	7500	180	150	50	120	100	80	200
21	HT soya	3	9	3000	125	400	50	120	100	80	200
22	HT rape	3	9	3000	75	350	50	120	100	80	200
23	IR cotton	2	9	1500	250	2500	50	120	100	100	200
24	GM sugarbee	3	10	60000	250	40	50	120	100	100	200

Table 2 – Technical data



Crops		pest damage rate	weed damage rate	vul to drought
1	winterwheat	0.98	1	1
2	springwheat	1	1	1
3	feedmaize	1.2	1	1
4	soya	1	1	1
5	rape	1	1.05	1
6	cotton	1	1	1
7	potato	1	1	1
8	sugarbeet	1	1	1
9	rice	1	1	1
10	winterbarley	0.98	1	1
11	springbarley	1	1	1
12	sunflower	1	1	1
13	legume	1	1	1
14	durumwheat	1	1	1
15	rye	1	1	1
16	triticale	1	1	1
17	fallow	0	0	0
18	HT maize	1	1	1
19	IR maize	1	1	1
20	HTIR maize	1	1	1
21	HT soya	1	1	1
22	HT rape	1	1	1
23	IR cotton	1	1	1
24	GM sugarbeet	1	1.2	1

Table 3 – Management data

Crops		tillage	pesticide	herbicide	irrigate
1	winterwheat	1	1	1	0
2	springwheat	1	1	1	0
3	feedmaize	0	1	1	1
4	soya	0	0	0	0
5	rape	0	1	1	0
6	cotton	0	0	0	0
7	potato	0	0	0	0
8	sugarbeet	0	0	1	0
9	rice	0	0	0	0
10	winterbarley	0	1	1	0
11	springbarley	0	0	0	0
12	sunflower	0	0	0	0
13	legume	1	0	0	0
14	durumwheat	0	0	0	0
15	rye	0	0	0	0
16	triticale	0	0	0	0
17	fallow	0	0	0	0
18	HT maize	0	1	1	1
19	IR maize	0	1	1	1
20	HTIR maize	0	1	1	1
21	HT soya	0	0	0	0
22	HT rape	0	1	1	1
23	IR cotton	0	0	0	0
24	GM sugarbeet	0	0	1	0

Appendix A

A1 Single cultivation – example of conventional vs IR, HT and HTIR maize

		Costs and returns, €/ha:					Pressures (0-100%):		
crop:	yield-kg/ha	seed	control	sales	margin	time	pest	weed	drought
feedmaize	7500	125	0	1125	1000	16:37:06	0.0	0.0	0.0
feedmaize	7375	125	0	1106	981	16:37:09	10.0	0.0	0.0
feedmaize	7425	125	100	1114	889	16:37:12	20.0	0.0	0.0
feedmaize	7390	125	100	1108	883	16:37:14	30.0	0.0	0.0
feedmaize	7353	125	100	1103	878	16:37:17	40.0	0.0	0.0
feedmaize	7263	125	100	1089	864	16:37:19	50.0	0.0	0.0
feedmaize	7170	125	100	1076	851	16:37:22	60.0	0.0	0.0
feedmaize	7423	125	200	1113	788	16:37:24	70.0	0.0	0.0
feedmaize	7410	125	200	1112	787	16:37:26	80.0	0.0	0.0
feedmaize	7399	125	200	1110	785	16:37:29	90.0	0.0	0.0
feedmaize	7389	125	200	1108	783	16:37:32	100.0	0.0	0.0
feedmaize	7500	125	0	1125	1000	16:37:41	0.0	0.0	0.0
feedmaize	7345	125	0	1102	977	16:37:44	0.0	10.0	0.0
feedmaize	7379	125	100	1107	882	16:37:47	0.0	20.0	0.0
feedmaize	7270	125	100	1090	865	16:37:49	0.0	30.0	0.0
feedmaize	7118	125	100	1068	843	16:37:52	0.0	40.0	0.0
feedmaize	7379	125	200	1107	782	16:37:54	0.0	50.0	0.0
feedmaize	7354	125	200	1103	778	16:37:57	0.0	60.0	0.0
feedmaize	7300	125	200	1095	770	16:38:00	0.0	70.0	0.0
feedmaize	7239	125	200	1086	761	16:38:02	0.0	80.0	0.0
feedmaize	7178	125	200	1077	752	16:38:05	0.0	90.0	0.0
feedmaize	7118	125	200	1068	743	16:38:08	0.0	100.0	0.0
IR maize	7500	150	50	1125	925	16:38:24	0.0	0.0	0.0
IR maize	7499	150	50	1125	925	16:38:28	10.0	0.0	0.0
IR maize	7497	150	50	1125	925	16:38:32	20.0	0.0	0.0
IR maize	7496	150	50	1124	924	16:38:35	30.0	0.0	0.0
IR maize	7495	150	50	1124	924	16:38:38	40.0	0.0	0.0
IR maize	7493	150	50	1124	924	16:38:41	50.0	0.0	0.0
IR maize	7492	150	50	1124	924	16:38:43	60.0	0.0	0.0
IR maize	7490	150	50	1124	924	16:38:46	70.0	0.0	0.0
IR maize	7489	150	50	1123	923	16:38:49	80.0	0.0	0.0
IR maize	7488	150	50	1123	923	16:38:52	90.0	0.0	0.0
IR maize	7486	150	50	1123	923	16:38:54	100.0	0.0	0.0
HT maize	7500	150	130	1125	845	16:39:14	0.0	0.0	0.0
HT maize	7470	150	130	1120	841	16:39:17	0.0	10.0	0.0
HT maize	7439	150	130	1116	836	16:39:20	0.0	20.0	0.0
HT maize	7409	150	130	1111	831	16:39:23	0.0	30.0	0.0
HT maize	7379	150	130	1107	827	16:39:26	0.0	40.0	0.0
HT maize	7345	150	130	1102	822	16:39:28	0.0	50.0	0.0
HT maize	7270	150	130	1090	811	16:39:31	0.0	60.0	0.0
HT maize	7194	150	130	1079	799	16:39:34	0.0	70.0	0.0
HT maize	7118	150	130	1068	788	16:39:37	0.0	80.0	0.0
HT maize	7042	150	130	1056	776	16:39:39	0.0	90.0	0.0
HT maize	7379	150	210	1107	747	16:39:42	0.0	100.0	0.0
feedmaize	7500	125	0	1125	1000	16:40:00	0.0	0.0	0.0
feedmaize	7037	125	0	1056	931	16:40:04	10.0	10.0	0.0
feedmaize	7235	125	200	1085	760	16:40:10	20.0	20.0	0.0
feedmaize	6987	125	200	1048	723	16:40:15	30.0	30.0	0.0
feedmaize	6519	125	200	978	653	16:40:18	40.0	40.0	0.0
feedmaize	6953	125	300	1043	618	16:40:23	50.0	50.0	0.0
HTIR maize	7500	180	130	1125	815	16:40:36	0.0	0.0	0.0
HTIR maize	7468	180	130	1120	810	16:40:40	10.0	10.0	0.0
HTIR maize	7437	180	130	1115	806	16:40:46	20.0	20.0	0.0
HTIR maize	7405	180	130	1111	801	16:40:50	30.0	30.0	0.0
HTIR maize	7373	180	130	1106	796	16:40:55	40.0	40.0	0.0
HTIR maize	7328	180	130	1099	789	16:41:01	50.0	50.0	0.0

A2 Five years continuous cultivation – conventional vs IR maize

		Costs and returns, €/ha:				Pressures (0-100%):
crop:	yield-kg/ha	seed	control	sales	margin	pest
feedmaize	7500	125	0	1125	1000	0
	7500	125	0	1125	1000	
	7500	125	0	1125	1000	
	7500	125	0	1125	1000	
	7500	125	0	1125	1000	
feedmaize	7419	125	100	1113	888	10
	7335	125	0	1100	975	
	7423	125	100	1113	888	
	7349	125	0	1102	977	
	7423	125	100	1113	888	
feedmaize	7344	125	100	1102	877	20
	7411	125	100	1112	887	
	7347	125	0	1102	977	
	7415	125	100	1112	887	
	7360	125	0	1104	979	
feedmaize	7411	125	200	1112	787	30
	7198	125	0	1080	955	
	7389	125	100	1108	883	
	7346	125	0	1102	977	
	7413	125	100	1112	887	
feedmaize	7389	125	200	1108	783	40
	7162	125	0	1074	949	
	7393	125	100	1109	884	
	7263	125	0	1089	964	
	7404	125	100	1111	886	
feedmaize	7360	125	200	1104	779	50
	7414	125	100	1112	887	
	7329	125	0	1099	974	
	7420	125	100	1113	888	
	7380	125	0	1107	982	
feedmaize	7211	125	200	1082	757	60
	7391	125	100	1109	884	
	7313	125	0	1097	972	
	7420	125	100	1113	888	
	7358	125	0	1104	979	
feedmaize	7266	125	200	1090	765	70
	7411	125	100	1112	887	
	7276	125	0	1091	966	
	7417	125	100	1113	888	
	7371	125	0	1106	981	
feedmaize	7403	125	300	1110	685	80
	7340	125	0	1101	976	
	7144	125	0	1072	947	
	7388	125	100	1108	883	
	7133	125	0	1070	945	
feedmaize	7420	125	300	1113	688	90
	7348	125	0	1102	977	
	7417	125	100	1113	888	
	7353	125	0	1103	978	

	7127	125	0	1069	944	
feedmaize	7402	125	300	1110	685	100
	7367	125	0	1105	980	
	7223	125	0	1083	958	
	7379	125	100	1107	882	
	7264	125	0	1090	965	
IR maize	7500	150	50	1125	925	0
	7500	150	50	1125	925	
	7500	150	50	1125	925	
	7500	150	50	1125	925	
	7500	150	50	1125	925	
IR maize	7484	150	50	1123	923	10
	7479	150	50	1122	922	
	7477	150	50	1122	922	
	7476	150	50	1121	922	
	7471	150	50	1121	921	
IR maize	7463	150	50	1119	920	20
	7467	150	50	1120	920	
	7461	150	50	1119	919	
	7451	150	50	1118	918	
	7451	150	50	1118	918	
IR maize	7446	150	50	1117	917	30
	7448	150	50	1117	917	
	7442	150	50	1116	916	
	7447	150	50	1117	917	
	7440	150	50	1116	916	
IR maize	7429	150	50	1114	914	40
	7403	150	50	1111	911	
	7401	150	50	1110	910	
	7393	150	50	1109	909	
	7403	150	50	1110	911	
IR maize	7423	150	50	1113	914	50
	7425	150	50	1114	914	
	7403	150	50	1110	911	
	7391	150	50	1109	909	
	7385	150	50	1108	908	
IR maize	7407	150	50	1111	911	60
	7412	150	50	1112	912	
	7416	150	50	1112	912	
	7415	150	50	1112	912	
	7419	150	50	1113	913	
IR maize	7381	150	50	1107	907	70
	7358	150	50	1104	904	
	7303	150	50	1095	896	
	7231	150	50	1085	885	
	7415	150	150	1112	812	
IR maize	7375	150	50	1106	906	80
	7371	150	50	1106	906	
	7369	150	50	1105	905	
	7365	150	50	1105	905	
	7352	150	50	1103	903	
IR maize	7267	150	50	1090	890	90
	7230	150	50	1085	885	
	7428	150	150	1114	814	

	7433	150	50	1115	915	
	7433	150	50	1115	915	
IR maize	7327	150	50	1099	899	100
	7344	150	50	1102	902	
	7323	150	50	1098	899	
	7360	150	50	1104	904	
	7371	150	50	1106	906	

A3 Five year crop rotation – wheat-sugarbeet-wheat-legume-wheat
(conventional vs herbicide-tolerant sugarbeet in year 2)

		Costs and returns, €/10 ha:				Pressures (0-100%):
crop:	yield-kg/ha	seed	control	sales	margin	weed
winterwheat	8000	600	0	12000	11400	0
sugarbeet	60000	2000	0	24000	22000	
springwheat	6000	600	0	9000	8400	
legume	1400	1090	0	3080	1990	
winterwheat	8000	600	0	12000	11400	
winterwheat	7535	600	0	11303	10703	10
sugarbeet	58073	2000	1000	23229	20229	
springwheat	5882	600	1000	8823	7223	
legume	1306	1090	0	2874	1784	
winterwheat	7694	600	1000	11541	9941	
winterwheat	7676	600	1000	11514	9914	20
sugarbeet	58807	2000	1000	23523	20523	
springwheat	5591	600	0	8387	7787	
legume	979	1090	0	2153	1063	
winterwheat	7803	600	2000	11705	9105	
winterwheat	7865	600	2000	11797	9197	30
sugarbeet	57328	2000	0	22931	20931	
springwheat	5827	600	1000	8740	7140	
legume	1257	1090	0	2765	1675	
winterwheat	7585	600	1000	11377	9777	
winterwheat	7789	600	2000	11683	9083	40
sugarbeet	55837	2000	0	22335	20335	
springwheat	5709	600	1000	8564	6964	
legume	1141	1090	0	2511	1421	
winterwheat	7860	600	2000	11790	9190	
winterwheat	7676	600	2000	11514	8914	50
sugarbeet	58807	2000	1000	23523	20523	
springwheat	5591	600	0	8387	7787	
legume	979	1090	0	2153	1063	
winterwheat	7803	600	2000	11705	9105	
winterwheat	7563	600	2000	11345	8745	60
sugarbeet	58222	2000	1000	23289	20289	
springwheat	5887	600	1000	8831	7231	
legume	1312	1090	0	2886	1796	
winterwheat	7716	600	1000	11574	9974	
winterwheat	7450	600	2000	11176	8576	70
sugarbeet	57626	2000	1000	23050	20050	
springwheat	5850	600	1000	8776	7176	

legume	1278	1090	0	2813	1723	
winterwheat	7629	600	1000	11443	9843	
winterwheat	7856	600	3000	11783	8183	80
sugarbeet	57029	2000	0	22812	20812	
springwheat	5803	600	1000	8705	7105	
legume	1235	1090	0	2717	1627	
winterwheat	7541	600	1000	11312	9712	
winterwheat	7834	600	3000	11751	8151	90
sugarbeet	56433	2000	0	22573	20573	
springwheat	5756	600	1000	8634	7034	
legume	1192	1090	0	2622	1532	
winterwheat	7454	600	1000	11181	9581	
winterwheat	7789	600	3000	11683	8083	100
sugarbeet	55837	2000	0	22335	20335	
springwheat	5709	600	1000	8564	6964	
legume	1141	1090	0	2511	1421	
winterwheat	7860	600	2000	11790	9190	
winterwheat	8000	600	0	12000	11400	0
GM						
sugarbeet	60000	2500	1499	24000	20001	
springwheat	6000	600	0	9000	8400	
legume	1400	1090	0	3080	1990	
winterwheat	8000	600	0	12000	11400	
winterwheat	7535	600	0	11303	10703	10
GM						
sugarbeet	59458	2500	1499	23783	19784	
springwheat	5893	600	0	8840	8240	
legume	1319	1090	0	2902	1812	
winterwheat	7744	600	1000	11616	10016	
winterwheat	7676	600	1000	11514	9914	20
GM						
sugarbeet	59567	2500	1499	23827	19828	
springwheat	5914	600	0	8872	8272	
legume	1343	1090	0	2956	1866	
winterwheat	7841	600	1000	11762	10162	
winterwheat	7865	600	2000	11797	9197	30
GM						
sugarbeet	59740	2500	1499	23896	19897	
springwheat	5949	600	0	8923	8323	
legume	1376	1090	0	3028	1938	
winterwheat	7645	600	0	11467	10867	
winterwheat	7789	600	2000	11683	9083	40
GM						
sugarbeet	59653	2500	1499	23861	19862	
springwheat	5932	600	0	8897	8297	
legume	1363	1090	0	2999	1909	
winterwheat	7446	600	0	11170	10570	
winterwheat	7676	600	2000	11514	8914	50
GM						
sugarbeet	59567	2500	1499	23827	19828	
springwheat	5914	600	0	8872	8272	
legume	1343	1090	0	2956	1866	
winterwheat	7841	600	1000	11762	10162	
winterwheat	7563	600	2000	11345	8745	60
GM	59480	2500	1499	23792	19793	

sugarbeet						
springwheat	5897	600	0	8846	8246	
legume	1324	1090	0	2912	1822	
winterwheat	7764	600	1000	11646	10046	
winterwheat	7450	600	2000	11176	8576	70
GM						
sugarbeet	59393	2500	1499	23757	19758	
springwheat	5880	600	0	8820	8220	
legume	1304	1090	0	2869	1779	
winterwheat	7685	600	1000	11527	9927	
winterwheat	7856	600	3000	11783	8183	80
GM						
sugarbeet	59723	2500	1499	23889	19890	
springwheat	5945	600	0	8918	8318	
legume	1375	1090	0	3025	1935	
winterwheat	7605	600	0	11408	10808	
winterwheat	7834	600	3000	11751	8151	90
GM						
sugarbeet	59688	2500	1499	23875	19876	
springwheat	5938	600	0	8908	8308	
legume	1371	1090	0	3016	1926	
winterwheat	7526	600	0	11289	10689	
winterwheat	7789	600	3000	11683	8083	100
GM						
sugarbeet	59653	2500	1499	23861	19862	
springwheat	5932	600	0	8897	8297	
legume	1363	1090	0	2999	1909	
winterwheat	7446	600	0	11170	10570	

Appendix B – Coding of assumptions in VBA

B1 – if the crop is GMO, then a ‘flat rate’ coexistence cost is assumed, irrespective of farm size.

```
    If ThisCropID > 17 Then CoexistenceCost = 499 Else CoexistenceCost = 0
```

B2 – if the crop is IR, the initial pest pressure is reduced by a fixed percentage.

```
    If (ThisCropID = 19 Or ThisCropID = 20 Or ThisCropID = 23 Or ThisCropID = 24) _
            Then CropIsIR = True
    If CropIsIR Then Pressure(1) = 0.1 * Pressure(1)
```

B3 – if the crop has been changed, the initial pest pressure is reduced by a fixed percentage.

```
    If CropID <> pCropID Then Pressure(1) = 0.8 * Pressure(1)
```

B4 – if the crop is HT, the initial weed pressure is reduced by a fixed percentage.

```
    If (ThisCropID = 18 Or ThisCropID = 20 Or ThisCropID = 21 Or ThisCropID = 22 _
            Or ThisCropID = 24) Then CropIsHT = True
    If CropIsHT Then Pressure(2) = 0.2 * Pressure(2)
```

- and one-off cost/ha of glyphosate or equivalent application is charged.

```
    DisAgg(calyr, 3) = DisAgg(calyr, 3) + (econData(ThisCropID, 9) * PlotSize)
```

B5 - potential yield (subject to modification by pressures) from known performance data.

```
    YieldThisCrop = econData(ThisCropID, 3)
```

B6 – if previous crop was legume, this enhances potential yield by fixed percentage.

```
    If pCropID = 13 Then YieldThisCrop = 1.05 * YieldThisCrop
```

B7 - if previous year was fallow, initial weed pressure is increased by fixed percentage.

```
    If pCropID = 17 Then Pressure(2) = 1.2 * Pressure(2)
```

B8 - if previous crop IR, then initial pest pressure reduced by fixed percentage.

```
    If pCropIR Then Pressure(1) = 0.75 * Pressure(1)
```

B9 - if previous crop HT, then initial weed pressure reduced by fixed percentage.

```
    If pCropHT Then Pressure(2) = 0.9 * Pressure(2)
```

B10 – one-off cost/ha is charged if Tillage or Min-Tillage selected.

```
    If Tillage = 1 Then TillageCost = econData(ThisCropID, 6)
    If Tillage = 2 Then TillageCost = econData(ThisCropID, 7)
```

B11 – if tillage is carried out, then weed pressure reduced to ¼ or 1/3 of previous pressure.

```
    Pressure(3) = (1 / (Tillage + 2)) * Pressure(3)
```

B12 – seed and tillage charged at specified rates.

```
    DisAgg(calyr, 2) = DisAgg(calyr, 2) + (econData(ThisCropID, 4) * PlotSize)
    DisAgg(calyr, 3) = DisAgg(calyr, 3) + (TillageCost * PlotSize)
```

In each month that crop is in ground, update pressures.

B13 – pest pressure fluctuates randomly, but also increases at a rate linked to scientific data.

```
    Pressure(1) = (1 + (0.2 * Rnd())) * Pressure(1) * sciData(ThisCropID, 1)
```

B14 – but pest attrition if crop is IR

```
    If CropIsIR Then Pressure(1) = 0.925 * Pressure(1)
```

B15 – weed pressure increases exponentially

```
    Pressure(2) = 1.12 * Pressure(2)
    If CropIsHT Then Pressure(2) = 0.925 * Pressure(2)
```

B16 – drought pressure dependent on region

```
    If (iRegion = 1 Or iRegion = 2) Then
        Pressure(3) = 1.006 * Pressure(3)
        Else
        Pressure(3) = 1.003 * Pressure(3)
        End If
```

B17 – if strategy chosen, then decision to apply pesticide made when pest pressure reaches threshold

```
    If (mgmtData(ThisCropID, 2) And Pressure(1) > 15) Then
        Pressure(1) = 0.3 * Pressure(1)
```

- and cost of treatment/ha is charged.

```
        DisAgg(calyr, 3) = DisAgg(calyr, 3) + (econData(ThisCropID, 8) * PlotSize)
        End If
```

B18 - if strategy chosen, then decision to apply herbicide made when weed pressure reaches threshold

```
    If (mgmtData(ThisCropID, 3) And Pressure(2) > 12) Then
        Pressure(2) = 0.4 * Pressure(2)
```

- and cost of treatment/ha is charged.

```
        DisAgg(calyr, 3) = DisAgg(calyr, 3) + (econData(ThisCropID, 9) * PlotSize)
        End If
```

B19 - if strategy chosen, then decision to irrigate made when drought pressure reaches threshold

```
    If (mgmtData(ThisCropID, 4) And Pressure(3) > 12) Then
        Pressure(3) = 0.2 * Pressure(3)
```

- and cost of treatment/ha is charged.

```
        DisAgg(calyr, 3) = DisAgg(calyr, 3) + (econData(ThisCropID, 10) * PlotSize)
        End If
```

B20 – find sum of pressures, then look up new predicted yield from formula in worksheet “yield”

```
    CurrentPressure = 0
        For i = 1 To 3
            CurrentPressure = CurrentPressure + Pressure(i)
```

```
            Next i
        If CurrentPressure > 99 Then CurrentPressure = 99
Worksheets("yield").Cells(2, 1).Value = CurrentPressure
YieldThisCrop = (Worksheets("yield").Cells(2, 2).Value/100)*econData(ThisCropID, 3)
```

B21 – at harvest, crop value is given by forecast yield and commodity price.

```
    ValueThisCrop = PlotSize * (YieldThisCrop / 1000) * econData(ThisCropID, 5)
```