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The Extent to which Potential Benefits to EU Farmers of Adopting Transgenic Crops are Reduced by Cost of Compliance with Coexistence Regulations

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This article forecasts the extent to which the potential benefits of adopting transgenic crops may be reduced by costs of compliance with coexistence regulations applicable in various member states of the EU. A dynamic economic model is described and used to calculate the potential yield and gross margin of a set of crops grown in a selection of typical rotation scenarios. The model simulates varying levels of pest, weed, and drought pressures, with associated management strategies regarding pesticide and herbicide application, and irrigation. We report on the initial use of the model to calculate the net reduction in gross margin attributable to coexistence costs for insect-resistant (IR) and herbicide-tolerant (HT) maize grown continuously or in a rotation, HT soya grown in a rotation, HT oilseed rape grown in a rotation, and HT sugarbeet grown in a rotation. Conclusions are drawn about conditions favoring inclusion of a transgenic crop in a crop rotation, having regard to farmers' attitude toward risk.

Key words: biotechnology, coexistence, crop rotation, economic, modelling, risk, transgenic.

Introduction

Since the first wide-scale planting of transgenic crops, the area grown globally has expanded rapidly with about 170 million ha grown in 2012—principally maize, cotton, soya, and canola. There were five countries (United States, Brazil, Argentina, Canada, and India) in which transgenic crops were grown on more than 10M ha (James, 2013). Of the established transgenic crops, only insect-resistant (IR) maize is approved for cultivation in the European Union (EU), and that crop is grown mainly in Spain and Portugal. Some of the other established transgenic crops could potentially be profitable for farmers to adopt in some parts of Europe (Park, McFarlane, Phipps, & Ceddia, 2011), but it is likely that the improvement in gross margin relative to a conventional crop would be offset by the cost to the farmer of compliance with coexistence regulations.

Many previous studies have been published concerning the economic impact of transgenic crops, and a few of these economic studies have been based on the formal representation of economic models. Some examples include the following.

- Anderson and Cavendish (2001) developed a dynamic simulation framework for exploring policy options in order to assess the role of technical developments in relation to environmental protection policy, permitting the introduction of time lags, and effects of changing preferences.
- In the research project "Sustainable Introduction of GMOs into European Agriculture" (SIGMEA), which was funded by the Sixth Framework Programme of the European Commission, Gómez-Barbero and Rodríguez-Cerezo (2006) estimated the global economic welfare generated by adoption of four dominant transgenic crops. They concluded that [at that time] on-farm benefits were derived from reducing production costs.
- Spatial effects of the introduction of transgenic crops were modelled by Munro (2008), who noted that coexistence with conventional crops is associated with strong regulation on planting patterns.
- Bohanec et al. (2008) reported on use of a qualitative multi-attribute by using a system known as DEXi, described as the largest and most integrative model developed within the ECOGEN (EC Framework 5) 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.
- The System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS; van Ittersum et al., 2008) modelling framework.

AMIGA (Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems) is a current project funded by the European Commission under the Framework Programme 7 to produce scientific data related to the possible environmental and economic impacts of cultivation of transgenic crops relevant to European environments. As part of the AMIGA project, a dynamic model of the economic performance of transgenic crops cultivated in rotation with other conventional crops has been developed, using some of the modelling concepts described in the works cited above.

In this article we report preliminary results obtained from the model for IR and herbicide-tolerant (HT) maize grown in a rotation, HT soya grown continuously or in a rotation, HT oilseed rape grown in a rotation, and HT sugarbeet grown in a rotation. These scenarios have been selected based on crop rotation researches (Benjamin, Milne, Parsons, Cussans, & Lutman, 2009; Castellazi et al., 2008; Colbach, Granger, & Meziere, 2013) that suggest that these events are both potentially available and could have benefits if grown with the EU. The article concludes by discussing briefly the likely take-up rate given farmers' attitudes to risk.

Description of the Model

The model of economic consequences of transgenic crops in the EU (METE) dynamic simulation model has been constructed to provide individual crop or rotational gross-margin output. The model has been constructed in Microsoft Visual Basic.

Time period: Crop rotations typically extend over two to seven years; the model accommodates scenarios of crop sequences adopted over any period within this range. This enables the effects of crop and crop management choices on subsequent crops to be modelled.

Time step: As the model is an economic model as opposed to a model of crop development, we considered 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 largely set by the need to provide separation from conventional crops on adjacent land, 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 user can specify average field sizes between 5 and 80 ha.

Five regions: The AMIGA field research is based on five biogeographic regions: Atlantic (Ireland, UK, Denmark, Netherlands, Belgium, Portugal, Luxembourg), Boreal (Finland, Sweden, Estonia, Latvia, Lithuania), Continental (Austria, Germany, Slovakia, Hungary, Czech Republic, Poland, Slovenia), Mediterranean (France, Italy, Spain, Cyprus, Greece, Malta), and Balkans (Bulgaria, Romania). The model has been designed to distinguish between these regions.

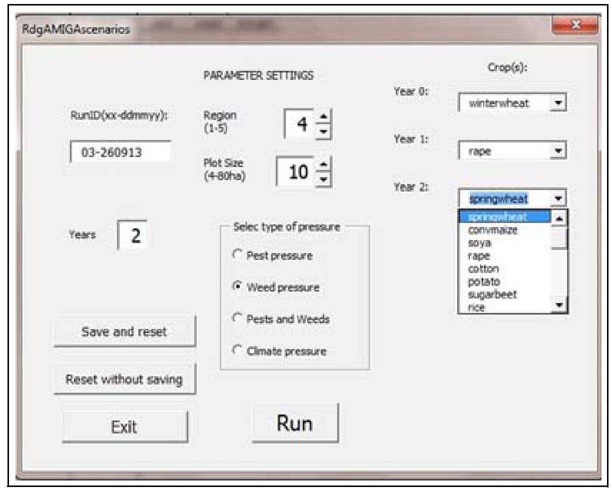

Figure 1. Form for selecting simulation details.

Choice of sets of crops: The model allows the selection of conventional crops and crop sequences that are common in a given biogeographic region. Where theoretically appropriate, 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 from Brookes (2012). Further costs taken into account are the costs of tillage, pesticides, and herbicides, together with, for some regions and crops, the cost of irrigation. This data was derived from Lang (2011) and Nix (2013).

Model calculations are initiated from a user form (Figure 1) after specifying

- the crops in the rotation is specified (up to 7 crops or a single continuous crop),
- the region,
- the plot size,
- the pressure or combination of pressures, and
- a file identifier for output data storage.

The model computes the predicted variations in yield of each crop in a cycle of continuous growth 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. Simulation proceeds in 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 and the management decisions associated with these pressures. Potential yield variation in response to the various pressures is calculated using coefficients obtained from published data (i.e., Brookes, 2005; Fulton & Keyowski, 1999; Gómez-Barbero, Berbel, & Rodríguez-Cerezo, 2008; Otiman, Badea, & Buzdugan, 2008).

Model Assumptions

The 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. Then the potential yield is recalculated as an empirical function of

- 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; and
- 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 effects 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, pesticide is applied if that is the management policy selected. If crops are grown in rotation, pest pressure is reduced with a change of host crop. If the crop is IR, it is assumed that the pest population is greatly reduced by the toxin exuded by that crop, which also results in reduced pest pressure for a subsequent crop. Similar assumptions are made in relation to weed pressure and drought pressure, if crops modified for these traits were to be planted.

Impairment of potential yield due to multiple simultaneous pressures is assumed to be 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).

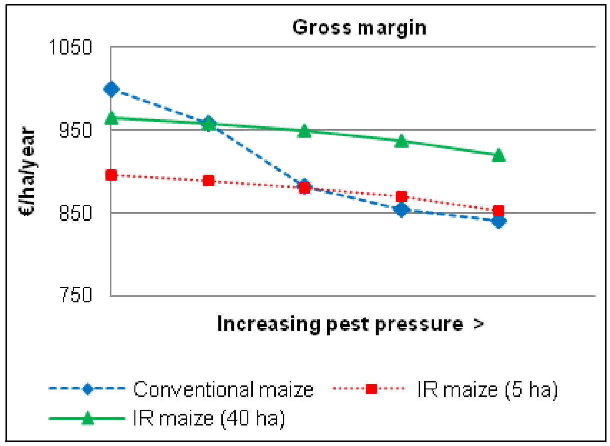

Figure 2. Model outcomes for conventional and Bt maize.

Model Validation

Model validation has been undertaken; this shows that the 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 (Gómez-Barbero et al., 2008). Ex-post data on the performance of Bt maize in the Czech Republic (Kocourek & Stara, 2012) confirmed yield losses of 10% to 15% of conventional maize under pressure from the European corn borer (ECB) in 50% of fields, with Bt maize being 100% effective in preventing loss of yield.

Bt maize MON810 is the only transgenic cereal crop approved for cultivation in the EU. In Figure 2, the gross margin per hectare is predicted for a maize crop affected by pest pressure. The model outcomes are consistent with the evidence from Spain, and indicate that for a large field, i.e. 40 ha, the cost of Bt technology and the cost of compliance with coexistence regulations reduce the gross margin when pest pressure is absent, but the protection of crop yield provided by the technology has a positive impact on gross margin at most levels of pest pressure experienced in the maize-growing regions of Spain in which ECB is present. However, the cost of compliance with coexistence regulations is greater when maize is grown in small fields or blocks because the buffer zone forms a proportionately greater part of the field space. For a field or block of only 5 ha, the model predicts that coexistence costs reduce gross margin further by €60/ha, and the technology is then only beneficial in conditions of severe pest pressure. This is consistent with the incentive for 'clustering' of fields for transgenic crop cultivation assessed by Demont and Devos (2008), who noted their expectation that clustering will precede any implementation of costly coexistence measures. The findings of Ceddia,

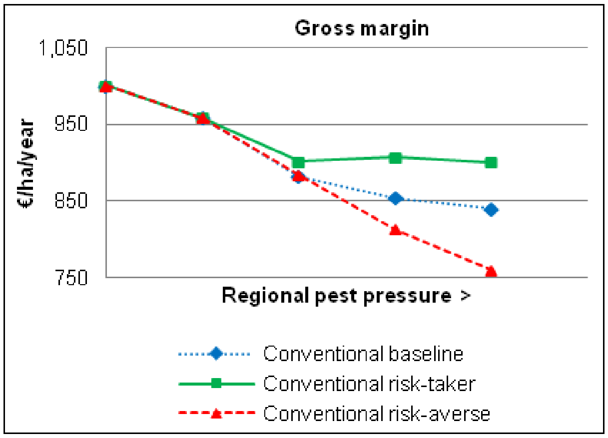

Figure 3. Effect of varying extent of managerial risk-taking with conventional maize.

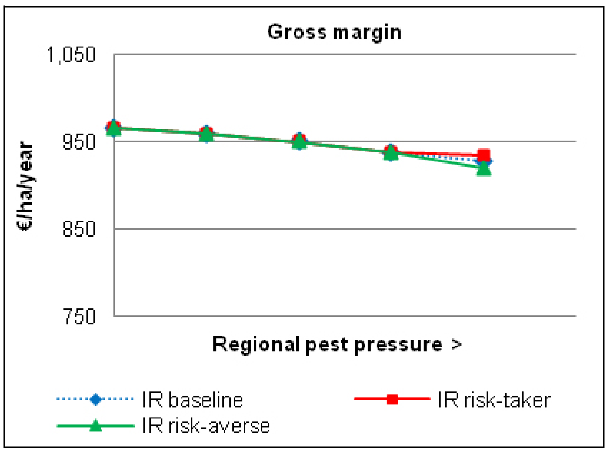

Figure 4. Effect of varying extent of managerial risk-taking with IR maize.

Bartlett, and Peddings (2009) concerning field size and clustering in their modelling of the effect of buffer zones, crop areas, and spatial aggregation with reference to HT oilseed rape confirm that increasing spatial aggregation reduces coexistence costs.

Sensitivity Analysis

There are various parameters that can be tested for sensitivity. For brevity, the sensitivity analysis illustrated here relates to the amount and timing of pesticide applied by farms growing continuous maize that may choose to adopt IR maize—the aim being to show how a farmer's perception of risk can influence model performance and predicted profitability. The first farm is the 'baseline,' where pesticide is used in recommended quantities, and the manager only applies additional pesticide when moderate pest damage is apparent. The second farm is a 'risk-taker' where the manager hopes to escape pest damage without the full recommended pesticide application, and delays further applications later than the 'baseline' manager. The third farm is 'risk-averse' and initially applies more than the recommended pesticide application and continues to spray even at moderate signs of pest damage.

Figure 3 shows the predicted outcomes for the three cases; the insurance cost to the 'risk-averse' farm tends to depress the gross margin achieved with conventional maize in a region where pest pressure is a known hazard.

Figure 4 shows the equivalent outcomes after adoption of IR maize; the inherent protection against pests provided by the IR trait provides all managements with confidence that pests will cause only minor damage, and attitudes to risk only become relevant at extreme levels of risk of pest damage. This reduces the sensitivity of gross margin to managerial decision making, as demonstrated in Figure 4.

Results

The model is readily adaptable for simulation of the economic performance of a wide range of crops grown continuously or in rotations, subject to a wide range of pressures and treatments. Here, the effects on gross margin for a selection of typical cultivation sequences in selected regions of the EU are reported. Typical gross margins for other crops grown in EU member states were taken from Brookes (2012) and from EU cereal farms report 2012 (European Commission, Directorate General for Agriculture and Rural Development, 2013).

Soyabean

Besides maize, the only other European transgenic crop for which data was available was the HT soyabean grown in Romania prior to accession into the EU. Using ex-post surveys of farmers who were early adopters in Romania, Brookes (2005) suggested gross margin improvements derived from improved yields and improved quality of seed, coupled with lower costs of production, but comparison was being made with low level of previous performance.

HT soyabean is the most widely grown of all GM crops, grown on 80M ha in 2012, and representing 81% of world production of soyabeans (James, 2013). However, only a few regions of Europe are suitable for soyabean cultivation. We have used data from the successful cultivation of HT soyabeans in Romania up to cessation (as a condition of accession to the EU; Brookes, 2005; Otiman et al., 2008) and cultivation elsewhere (Brookes

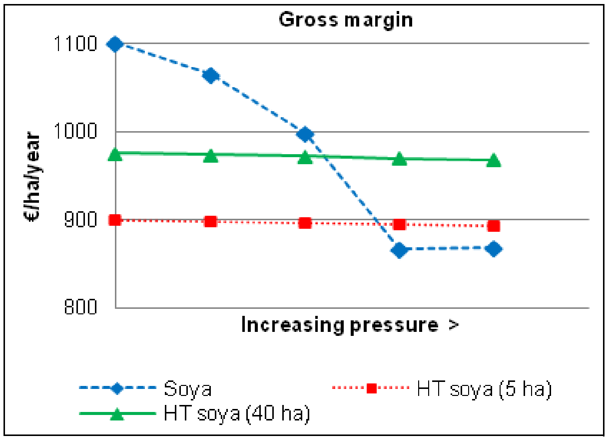

Figure 5. Model outcomes for conventional and HT soyabean.

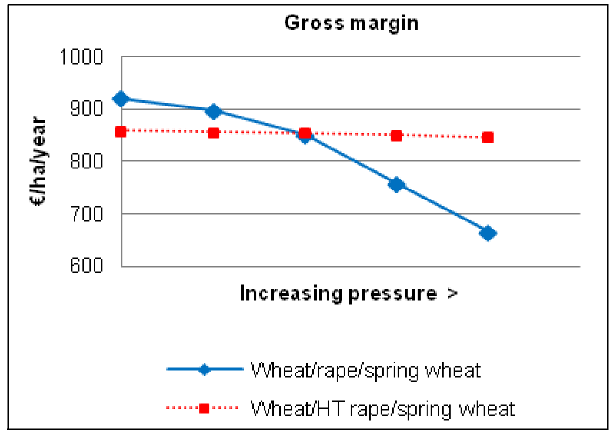

Figure 7. Oilseed rape in rotation with wheat (Region 3).

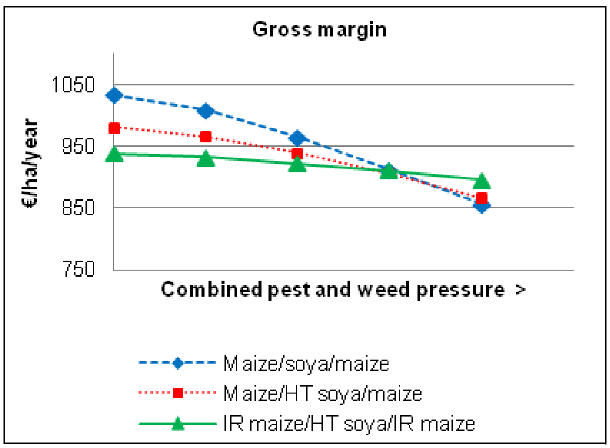

Figure 6. Soyabean in rotation with maize (Region 1).

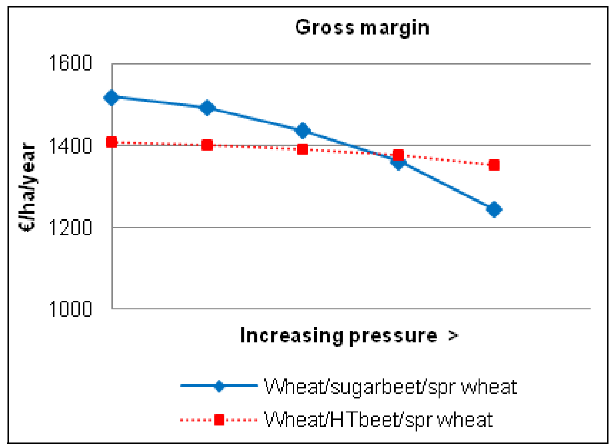

Figure 8. Sugarbeet in rotation with wheat (Region 4).

& Barfoot, 2009) to predict the gross margin for HT compared with conventional soyabeans. Simulations presented in Figure 5 suggest that there is likely to be little advantage in adopting HT soyabeans for small-scale cultivation when weed pressures are low; but, on a larger scale, the transgenic crop provides insurance against weed pressure. The simulation includes the assumption of 25% technology premium for HT soyabean seed, and if the supplier is able to offer a reduction in that premium, adoption of HT soyabean is correspondingly more likely to be profitable.

Soyabeans are frequently grown in rotation with maize, and Figure 6 shows the predicted combined effect of cultivation of Bt maize and HT soyabeans in place of conventional maize and soya in rotation involving both crops. The severe effect of pest damage on conventional maize tends to dominate over the minor advantage of adopting HT soya in a rotation of mainly conventional maize, but if IR maize is then adopted in place of conventional maize, gross margin is protected against both forms of pressure.

Oilseed Rape

Figure 7 shows model output for HT rape (canola) grown in place of conventional oilseed rape in rotation with milling wheat. The canola crop leaves the soil free from weed pressure—to the advantage of the subsequent wheat crop—to the extent that Canadian farmers are able to adopt a 'no-till' practice. In the simulation, there is an assumption that there is a small improvement in yield in the following wheat crop, but the model does not at this stage include a 'no-till' scenario.

Sugarbeet

Figure 8 shows the predicted benefit of substituting HT sugarbeet in rotation between winter milling wheat and spring wheat (data from Dillen, Demont, Tillie, &

Rodríguez-Cerezo, 2013). Under relatively low weed pressure, the conventional sugarbeet is predicted to offer a higher gross margin, but sugarbeet is known to be vulnerable to weed pressure.

Discussion

A common feature of all model results is that the direct cost of compliance with coexistence regulations is higher for farms that grow the crops on large contiguous areas or those that have near neighbors who grow conventional crops, because the cost of maintaining a buffer zone falls on the farm growing the transgenic crop. Indeed in the few instances where neighboring farms agree that they will all adopt a transgenic crop, the cost of coexistence can be vanishingly small (Skevas, Fevereiro, & Wesseler, 2010).

Other simulation runs demonstrate the use of the METE model to predict the performance of HT soyabean, oilseed rape, and sugarbeet if EU authorities permit cultivation of these HT crops in place of conventional crops.

- In the case of HT soyabeans, there is some evidence that HT soyabean cultivation would be profitable in itself, and that the aggregate gross margin from growing HT soyabean in rotation with conventional maize would be further enhanced. In regions where pest pressure on conventional maize is present, there may also be an economic advantage in replacing conventional maize with Bt maize in rotation with HT soyabean.
- In the case of HT oilseed rape, the model predicts a good probability of improvement in aggregate gross margin in rotations that include wheat, including a prediction based on evidence from Canada that the elimination of weeds associated with adoption of HT oilseed rape has a beneficial effect on economic performance of a following wheat crop. However, it should be noted that many of the assumptions of the model are based around the short-season canola varieties grown in Canada, whereas significant areas of the EU grow longer-season winter varieties.
- In the case of HT sugarbeet, there is a known vulnerability of conventional sugarbeet to weed pressure (Dewar, Haylock, Bean, & May, 2000), and the model predicts a strong probability that the aggregate gross margin of HT sugarbeet in rotation with wheat would exceed that of conventional sugarbeet in a similar rotation.

Conclusion

Initial simulation runs of the METE model suggest it can provide a useful tool to outline some of the gross margin implications of introducing GM crops into existing crops, or growing crops continuously (as with maize in some areas). Further work is needed to calibrate weed, pest, and drought pressure against empirical yield data so that the model can more accurately predict the point at which the use of GM varieties is likely to become profitable to the farmer. This “tipping” point is also dependent on the coexistence measures required in a particular growing region.

Nonetheless, the way in which the cost of compliance with regulations for coexistence of transgenic crops with conventional crops in EU arable farming falls entirely on the adopter of the transgenic crop presents a significant economic disincentive for transgenic crop adoption. Overall, the preliminary outcomes from our model suggest that there are numerous crop rotation scenarios where weed and pest pressures are high, in which the aggregate economic outcome could potentially lead to greater profit for the farmer if established transgenic crop varieties replaced conventional equivalent crops.

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