Assessing the indirect and long-term ecological impacts of innovation in agriculture is a real challenge: the GM example

Oléagineux, Corps Gras, Lipides. Volume 10, Numéro 3, 195-7, Mai 2003, Colza : enjeux et nouvelles synergies de la recherche, RECHERCHE

Auteur(s) : Antoine MESSÉAN, Frédérique ANGEVIN, Nathalie COLBACH, Jean-Marc MEYNARD , Unité Eco-innov, INRA, BP 01, 78850 Thiverval-Grignon, France <messeangrignon.inra.fr> <angevinjouy.inra.fr>. CETIOM, BP 04, 78850 Thiverval-Grignon, France. UMR Biologie et Gestion des Adventices, INRA, BP 86510, 17 rue Sully, 21065 Dijon Cedex, France <colbachdijon.inra.fr>. Département Systèmes Agraires et développement, INRA, BP 01, 78850 Thiverval-Grignon, France <meynardgrignon.inra.fr> .

Author(s) : Antoine MESSÉAN, Frédérique ANGEVIN, Nathalie COLBACH, Jean-Marc MEYNARD

Summary : All innovation in agriculture constitutes a significant and complex ecological disturbance, even if limited to a single and simple action. Indeed, whatever the nature and objective of the action, a large number of ecological processes are affected and numerous discontinuities may occur within the agro-ecosystem, in both time and space. As the GMO example illustrates, it is not sufficient to focus on direct effect of innovation, it is necessary to forecast mid- and long-term impacts of innovation with respect to the environment. Modelling phenomena appear then to be a key element to achieve this goal.

Keywords : Innovation, ecological impact, cost\\benefits balance, GM plants, co-existence, gene flow models

ARTICLE

Auteur(s) : Antoine MESSÉAN[1,2], Frédérique ANGEVIN[1], Nathalie COLBACH[3], Jean-Marc MEYNARD[4]

[1] *Unité Eco-innov, INRA, BP 01, 78850 Thiverval-Grignon, France*
<messean@grignon.inra.fr>
<angevin@jouy.inra.fr>.
[2] *CETIOM, BP 04, 78850 Thiverval-Grignon, France.*
[3] *UMR Biologie et Gestion des Adventices, INRA, BP 86510, 17 rue Sully, 21065 Dijon Cedex, France*
<colbach@dijon.inra.fr>.
[4] *Département Systèmes Agraires et développement, INRA, BP 01, 78850 Thiverval-Grignon, France*
<meynard@grignon.inra.fr>

Although agriculture has evolved during the last decades, with new requirements in terms of multifonctionnality, it remains one of the major human activities that contribute to sharpening our environment and rural development. Furthermore, the role of innovation has been essential for improving the competitiveness of agricultural systems: genetics through new varieties, crop protection through agrochemicals, new cropping systems, etc. It can be stated that the innovation process will remain one of the major factors for achieving the new objectives assigned to agriculture: reduce the negative impacts on the environment, ensure the food safety and contribute to a sustainable development.

As a matter of fact, all agricultural practices constitute a significant and complex ecological disturbance, even if limited to a single and simple action. Indeed, whatever the nature and objective of the action, a large number of ecological processes are affected and numerous discontinuities may occur within the agro-ecosystem, in both time and space.

Any change in technical practice (e.g. the introduction of GM crops, new conventional varieties, new chemical inputs, changes in the cropping system or in soil tillage) may therefore lead to changes in ecosystems, of various degrees of significance, through ecological processes and interactions with other agricultural practices. Such changes may have widespread socio-economical consequences. These changes affect not only the cultivated areas, but also the ecosystem as a whole and the natural environment. Furthermore, as successive operations within the field are interdependent, any change in one operation may necessitate modifications of various extents to the other operations or to the cropping system. The introduction of a new variety with a high level of resistance to a major disease may lead to decrease in chemical applications, or may even render chemical application entirely unnecessary. It may also make shorter rotations feasible. When assessing ecological impact, it is not sufficient to focus only on the direct effect of innovation; it is also necessary to take into account indirect and systemic effects.

Any innovation – whether a new technology or a technology already in use but extended to a new ecological context – thus requires studies aimed at forecasting ecological effects and assessing the cost/benefit balance.

Current responses are either extremely partial (*a priori* appraisal of the acute toxicity of chemical inputs on animal models, estimation of gene dispersal curves) or global (loss of biodiversity and fixed carbon during deforestation). Although various research projects have been carried out in this field, our ability to forecast the ecological fate of an innovation therefore remains poor. This may partly account for the increasing gap between science and society and the lack of confidence in public decision-making.

The GMO example

Although the development of GMOs provides an example of the weakness of current ecological impact prediction, the problem is not limited to this case and applies to all sorts of innovation.

Genetically Modified (GM) Crops are now widely grown in North America and, to a lesser extent, in other regions of the world (South America and Asia). Meanwhile, in the European Union, apart from some Bt corn commercial releases in Spain, only cultivation for experimental purposes is, in practice, carried out. A moratorium has been decided in different European countries and, due to environment and food safety concerns, new regulation rules are reinforcing the pre-marketing evaluation and traceability of novel products (e.g. Directive 2001/18). Recently, the Commission discussed the issue of co-existence which “has its origin in the principle that farmers should be able to cultivate freely the agricultural crops they choose, be it GM, conventional or organic”. However, with the development of GM crops, new concerns have been raised and are now at the heart of major debates and public interest.

A large amount of information dealing with direct effects of GM crops on the environment as well as on human health has been produced over the last ten years and is readily available. However, up until recently, specific experiments on a particular phenomenon and a specific GM crop were the main approach for providing basic scientific results and backing up policy-making decisions. This information remains fragmented and there is still urgent need for integrating knowledge from these specific studies. Furthermore, the evaluation process has to be performed not only on a case-by-case basis (to take into account the specific characteristics of each GM crop in terms of traits or plant biology) but also by addressing the interactions between GM crops and their indirect and delayed effects within the various agro-ecosystems.

Addressing these objectives is a real challenge for science as well as for regulation. On the one hand, new scientific approaches, methods and tools are required for such a systemic evaluation of the cost-benefit of GM crops. On the other hand, a new organisational framework for evaluation and monitoring of technologies has to be set up in order to address these new concerns.

New methodological tools for assessing systemic effects within the diversity of environmental systems in which GM crops may be cultivated are needed. Moreover, a sustainable management of GM crops requires the necessity to anticipate future changes, as far as it is possible through prospects: changes of agricultural practice to guarantee threshold levels of GM admixture, changes of environmental conditions due to modification of agricultural practices, future traits to be introduced in plants (introducing a herbicide resistance gene in wheat would lead to significant changes in the overall risk assessment balance for other herbicide tolerant crops).

If the pre-marketing evaluation process must be improved by taking into account systemic effects on the environment, it will never ensure that no unintended event might occur. A post-marketing monitoring system (to check that what was forecasted before marketing is still valid after) as well as a general surveillance (to detect any unexpected effect) must be implemented and reintegrated into the assessment process. In fact, the pre-marketing evaluation, mitigation measures and post-marketing monitoring must be parts of a continuous and iterative process aiming at ensuring an efficient and sustainable development of new technologies. Such a framework would contribute to a better confidence of European citizens in regulation processes and decision-making by increasing the amount of scientific information made available.

In order to take into account the various interractions between GM crops, farming systems and ecosystems, ecological studies at an integrative spatial scale should be considered. According to the concept developed in environmental sciences, the landscape scale is certainly the most relevant. Indeed, forecasting the fate of transgenes at the landscape level by taking into account the various cropping systems and the agricultural practices is necessary for assessing the impact of introducing GM crops within the very large range of existing production systems throughout Europe, for identifying ecological indicators and for setting up monitoring schemes. For such a perspective, specific experiments or studies carried out on a narrow basis are not sufficient even if some ecological impacts still have to be better known (e.g. gene horizontal transfer to micro organisms). Several studies have thus been carried out in order to broaden the scope of the evaluation: the inter-institute platforms in France [1] and the Farm Scale Evaluation programme in the UK [2].

Nevertheless, in order to forecast the spread and behaviour of transgenes and their impact a wide range of agro-ecosystems as well as for designing monitoring tools, modelling is a key element. Models help in:

– structuring knowledge, identifying gaps and reducing the research fragmentation;

– ranking farming systems according to gene flow behaviour;

– forecasting the behaviour of transgenes in cultivated and non-cultivated lands;

– *a priori* testing the efficiency of mitigation measures or regulation schemes;

– implementing monitoring schemes by identifying high risk situations;

– re-assessing the overall balance of the impacts of GM crops when new results are available (from trials as well as from monitoring).

Modelling to forecast the behaviour of transgenes has been in development for some years. It has been mainly focused on crop-to-crop gene flow and six models have been published so far. However, only two of them, GeneSys® for rapeseed [3, 4] and MAPOD® for corn [5], actually take into account the spatial patterns of landscapes and are able to forecast the behaviour of transgenes within the landscape. GeneSys® takes into account crop rotations as well as seed persistence. An adaptation of GeneSys® for sugar beet is under progress [6] and validation over a wide range of available data is being carried out.

Models have been used to underpin the co-existence studies carried out by INRA in France [7] and by JRC/IPTS study [8]. Results from these co-existence studies have raised several issues that research should address:

– There exists a wide range of farming systems within Europe that could not be addressed through specific studies. How should we represent or take into account this regional variability when assessing ecological and economical balances or designing regulation rules ?

– The landscape fragmentation has a great influence on gene flow and ecological impacts and its effect should be taken into account in modelling.

– Induced costs due to indirect effects of co-existence rules are difficult to estimate and are highly dependent on the local regional variability of landscapes and on agricultural farming systems.

– Available models for gene flow and ecological impacts mainly focus on the field level or on a small region (group of fields). However, mitigation measures and monitoring schemes should involve at least three different decision levels: the field level with crop management practices, the "cropping system" within the farming systems strategy, the landscape or the regional level. Up-scaling of models at different biogeographical levels should thus be made possible and easy to handle.

– Models should be made more generic in order to apply to a wide range of crops, especially those crops forthcoming, and should be more dynamic so that new impacts can be forecasted while keeping the basic gene flow structure.

All these elements lead to a key bottleneck: addressing the various ecological and economical factors and processes linked to GM impacts at the same common landscape level. To cope with these issues, several ongoing studies or programs have been launched over the last years. A special emphasis has to be given to the integration of current knowledge and the development of generic methods in order to set up a science-based framework, strategies, methods and tools for assessing ecological and economical balances of GM crops and for an effective management of their development within European farming systems.

REFERENCES

1. CHAMPOLIVIER J, GASQUEZ J, MESSEAN A, RICHARD-MOLARD M (1999). Management of transgenic crops within the cropping system In: Lutman, P.J.W. (ed.). Gene flow and Agriculture: Relevance for Transgenic Crops. British Crop Protection Council 1999 Symposium Proceedings No. 72, Farnham, UK, 233-40

2. FIRBANK LG, HEARD MS, WOIWOD IP, HAWES C, HAUGHTON A, CHAMPION G, SCOTT R, HILL MO, DEWAR A, SQUIRE GR, MAY M, BROOKS DR, BOHAN D, DANIELS RE, OSBORNE JL, ROY D, BLACK HIJ, ROTHERY, P, PERRY, JN (2003). An introduction to the Farm Scale Evaluations of genetically modified herbicide-tolerant crops, *Journal of Applied Ecology*, 40: 2-16.

3. COLBACH N, CLERMONT-DAUPHIN C, MEYNARD JM (2001a). GeneSys: A model of the influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape volunteers.
I. Temporal evolution of a population of rapeseed volunteers in a field. *Agric Ecosyst Environ*, 83: 235-53.

4. COLBACH N, CLERMONT-DAUPHIN C, MEYNARD JM (2001b). GeneSys: A model of the influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape volunteers.
II. Genetic exchanges among volunteer and cropped populations in a small region. *Agric Ecosyst Environ*, 83: 255-70.

5. ANGEVIN F, KLEIN E, CHOIMET C, MEYNARD JM, DE ROUW A, SOHBI Y (2001). Modélisation des effets des systèmes de culture et du climat sur les pollinisations croisées chez le maïs. Rapport du groupe 3 du programme de recherche *"Pertinence économique et faisabilité d'une filière 'sans utilisation d'OGM' "*. INRA – FNSEA, 56 p, pp 21-36.

6. SESTER M, COLBACH N, DARMENCY H (2002). Modelling the influence of cropping systems on gene flow herbicide resistant sugar beet. Presentation of the model GeneSys-Beet. VII Congress of the European Society of Agronomy, Cordoba, pp 327-8.

7. INRA (2001). Pertinence économique et faisabilité d'une filière 'sans utilisation d'OGM', rapports finaux.

1. Analyse économique de la propension des consommateurs à acheter des produits garantis « sans OGM » et choix du signal distinctif pertinent (coord. B. Ruffieux et S. Robin).
2. Elaboration d'un référentiel scientifique et technique permettant de caractériser les produits agricoles et alimentaires garantis « sans OGM » (coord. Y. Bertheau)
3. Isolement des collectes et maîtrise des disséminations au champ (coord. J. M. Meynard et M. Le Bail)
4. Analyse économique et réglementaire de l'organisation d'une filière « sans OGM » (coord. E. Valceschini et I. Avelange)

8. BOCK A-K, LHEUREUX K, LIBEAU-DULOS M, NILSAGARD H, RODRIGUEZ-CEREZO E (2002) “*Scenarios for co-existence of genetically modified, conventional and organic crops in European agriculture”,* Technical Report Series of the Joint Research Center of the European Commission, EUR 20394 EN.