A Conceptual Framework for the Design of Environmental Post-Market Monitoring of Genetically Modified Plants

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In 2004, 97% of worldwide commercially cultivated, genetically modified plants (GMP) were grown in five countries, i.e., USA, Argentina, Canada, Brazil, and China. None of these countries requires legally binding post-market monitoring (PMM) activities, or they are limited to very specific areas of concern, such as insect resistance monitoring of Bt maize, for example, in the United States. The regulatory frameworks of these countries recognize GM products that have received regulatory approval for commercialization if the products are substantially equivalent to comparable products with a history of safe use, and thus, do not present a greater risk. Environmental PMM or long-term health surveillance are therefore not considered necessary.

In regards to the possible environmental effects of GMPs, the principle of substantial equivalence is not followed in Europe, and a precautionary approach is chosen instead. Everyone who intends to commercially grow GM crops in the European Union (EU) is obligated to present a PMM plan to identify possible adverse effects on human health and the environment, which could arise directly or indirectly from the released GMP. To date, no EU-wide consensus on how to design such PMM programs has been defined, although monitoring concepts are currently being developed in several European countries. There is an urgent need for conceptual frameworks and guidance on how PMM programs should be planned and performed. The aim of our study was to develop a conceptual framework containing structures and procedures that could be used to implement such PMM programs. This framework should represent a pragmatic approach for feasible PMM programs that allow the assessment of possible environmental effects during commercial cultivation of GMP.

Procedure for the approval to cultivate GMPs in Europe

Each approval for commercial cultivation of a specific GMP has to be preceded by case-by-case risk assessments of potential adverse effects on the environment. Furthermore, the introduction of GMPs into the environment should generally be performed according to a step-by-step principle, which means that the scale of GMP releases can only be increased if a risk assessment of the preceding step has estimated an acceptable risk for the next step.

We established a scheme that clearly presents and distinguishes the different phases and activities of development and commercialization of a GMP (Fig. 1). Pre-market risk assessment (PMRA) is limited to the phase prior to approval for commercial cultivation, whereas PMM is limited to activities related to the commercial cultivation of GMPs. According to EU legislation, PMM is composed of two separate programs with different aims, i.e., case-specific monitoring (CSM) and general surveillance (GS).

Principles of environmental monitoring programs

We felt a strong need for a clear definition of the specific functions and differences of CSM and GS, as well as for a definition of what tasks should be accomplished in each program. In order to clearly distinguish the differences between the two programs, we analyzed the general principles of existing environmental monitoring programs. Based on these general principles, CSM and GS can be more clearly defined, and their respective limits can be identified:

1. Case-specific monitoring is intended to assess whether GMP-related adverse effects on the environment occur. It is based on specific risks that a particular GMP could present. CSM can be regarded as the continuation of the investigations performed during PMRA where defined hypotheses on possible anticipated effects are tested. The hypotheses can be confirmed or rejected after a defined period of time, after which CSM can be terminated (Fig. 1). As CSM is performed in close relation to the cultivation of a certain GMP, it should be possible to draw conclusions about the causes of detected changes. The gain of knowledge may lead to new questions, which have to be answered in specific risk assessment studies. CSM helps to reduce remaining uncertainties, and its results may influence the PMRA of new GMPs with comparable properties.

2. General surveillance is intended to detect unanticipated adverse environmental effects that were not identified and considered during pre-market risk assessment. Results obtained from GS cannot be linked to any specific attributes
of GMP cultivation, since the program provides a general assessment of the state of the environment, independent of any preconception. It can provide information on exceptional environmental changes, and possibly provide basic information to forecast the likely development of the environment. GS is not designed to determine the cause of possible environmental changes, as a multitude of factors could be involved. If environmental changes are observed, and it is considered likely that the cultivation of a specific GMP has caused them, the causality will have to be determined through specific risk assessment studies (Fig. 1).

Many existing monitoring programs face the problem of providing only limited information on quality and changes of the environment, because their purposes have not been exactly defined. We have identified clear conceptual differences between CSM and GS and propose to adopt separate frameworks when developing either of the two programs. Common to both programs is the need to put a value on possible ecological effects of GMP cultivation.

**Challenges for post-market-monitoring programs**

According to EU legislation, consent for commercial cultivation is given for a ten year period, after which the results of PMM and any other new information have to be presented in an environmental risk assessment to the competent authority in order to allow renewal of the consent. The time period chosen for PMM may be shorter than the ten year period given for the consent, but it could be extended beyond the consent period for detection of delayed effects. However, it is important to consider that the life-span of modern crop varieties may be shorter than the ten year period. For example, during the 1980s the average life-span of an oilseed rape cultivar was about ten years, but dropped to three years by 1997. It might therefore become difficult to perform CSM over an extended period of time for a specific GMP variety.
In CSM it may be difficult to relate environmental effects unambiguously to a specific GMP or its cultivation. All crops and all farming systems cause environmental impacts, and the effects detected could have been caused by factors other than the GMP. Intensification of agriculture, for example, has a range of impacts on biodiversity with widespread decline throughout many groups of organisms associated with farmland in Europe. An unbiased evaluation has to consider a reference system that displays the environmental effects that may occur without the cultivation of GMPs. Case-specific monitoring requires a comparable cropping system without GMP as a parallel control, where both crop systems are evaluated in parallel over the same time period. However, such a paired comparison might become difficult in practice, if, for example, the non-transgenic control is not cultivated in the same region or in a comparable agricultural landscape. An additional difficulty could arise from differences in crop management techniques for GM and non-GM plants. For example, GM herbicide-tolerant crops may be best managed by using a no-till strategy, while this technique may not be advisable for cropping systems based on conventionally bred plants. If a parallel control with a comparable cropping system without GMP is not possible, environmental impacts of GMP cultivation need to be compared based on general information of effects caused by current agricultural practice. While the cultivation of Bt maize, for example, may have weak effects on non-target arthropods, the use of a synthetic insecticide can significantly affect a large number of non-target arthropods.

Conclusions
Environmental post-market monitoring of genetically modified plants represents a new challenge for farmers, the agricultural industry, scientists, and regulators, since comparable environmental monitoring programs have not been established for conventional crops. However, the challenge to obtain information on the state of the environment is not new, and underlying principles have been established. Although these monitoring programs were originally designed for general environmental protection, the inherent principles also remain valid for environmental PMM of GMPs. The existing experience documented in the literature shows that monitoring programs require defined aims and a rigid structure in order to provide the desired information. Competent authorities will have to make decisions on maintaining consents for GMP cultivation based on the results of PMM. Case-specific monitoring and general surveillance have to be designed and implemented according to a pragmatic and realistic approach in order to be feasible. Competent authorities can support this approach by applying comparable valuation criteria for effects of GMP cultivation and for effects caused by current agricultural practice. We believe that our conceptual framework will be of assistance to industry, researchers, and regulators when assessing possible environmental effects of GMPs during commercialization.

Acknowledgements
We thank the Swiss Agency for the Environment, Forests and Landscape for partial funding of this study.

References
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