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Editorial

Pesticide use and risk reduction in European farming systems with IPM: An introduction to the special issue

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1. The need for durable and sustainable agriculture through innovation

The development and adoption of high-yielding varieties, improved agricultural techniques and rapid mechanization have contributed substantially to progress in agriculture since approximately the middle of the nineteenth century. This progress has led to the rapid increase in living standards in developed countries or the adequate standard of nutrition for the greater part of the world's population. Much of that improvement in agriculture was especially due to the substantial growth levels in the yields of important staple crops and especially their adequate protection through application of a wide range of conventional pesticides, which ensured a stable crop yield per unit area (Oerke, 2006).

The key objective in the nineteenth and most of the twentieth century agriculture was to increase productivity rather than durability and sustainability. Agriculture in the twenty-first century however faces the challenge of meeting food demands while satisfying sustainability goals. This is a difficult task to be addressed since food production and nature conservation compete for the same land (DeFries and Rosenzweig, 2010; Sayer et al., 2013). This is particularly true when one considers that there is a growing demand for agricultural products in markets of emerging economies, mainly in the most populated countries. Attaining food security and promoting food safety on a global scale, adaptation to climate and land use changes, and managing the loss of biodiversity and degradation of ecosystems are major challenges faced by society today.

To put agriculture in a perspective of sustainable development (Lichtfouse et al., 2009) a thorough rethink is needed in the orientation of agriculture and therefore ongoing changes call for a new wave of innovation. In this context, technological innovations are necessary for the development, implementation and adoption of sustainable crop protection systems (Ricci et al., 2011). The transition to new and sustainable agriculture needs to be accompanied by a change in nature of these innovations such as new ways of organizing research and/or setting priorities (Lamichhane et al., 2017, 2016a). It is either existing areas of innovation such as biological control (Bale et al., 2008) and varietal innovation or emerging technologies that improve the efficiency of crop protection, such as precision agriculture (Mahlein, 2016) or diagnostic tools based on molecular methods (Lucas, 2011). In addition to these technologies, breakthrough innovations on the organization of cropping systems are necessary to facilitate the transition to a truly integrated protection. Examples are the design of cropping systems and deployment of technologies on large spatial and temporal scales, the exploitation of biological regulation in agroecosystems or of ecological pest management strategies (Altieri, 1999; Altieri and Rogé, 2010; Lechenet et al., 2016; Lescourret et al., 2016). These are all levers to reduce biotic pressure and to prevent the development of resistance to pesticides or to contain circumvention of varietal resistance. Innovation is needed also in our own way of thinking while dealing with biotic stresses of crops. To this aim, the traditional "one crop/one pest/one year" approach has to be surpassed by "multi-year crop-pest interaction approaches" that allow for a durable and sustainable management of pests (pathogens, animal pests and weeds). Therefore, shift from an approach linking a product or a pest management technique in a cultivated plot to a comprehensive system approach — by understanding the complex interactions between pests, plants, natural enemies, agronomic and cultural practices and environment on an agro-ecosystems scale — implies a renovation of the innovation system. This renovation also includes the organization of research and innovation (R&I) as well as the practices and research methods (Birch et al., 2011; Savary et al., 2012).

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The current R&I system faces a real paradigm shift. Consequently, we have to question about our ability to design innovative systems without being dogmatic concerning their performance criteria or purpose. To this aim, there is a need to move toward a stimulation of the processes that contribute to the development of technologies/techniques and their assembly *in situ*. Therefore, it is a question of inspiring the innovative design approach where the objectives of the systems to be built, and the conditions of their validation and adoption, are not determined in advance (Meynard, 2008).

Current agricultural systems are characterized by a diversity of situations and strategies of the various operators of the food chain. The challenge for R&I therefore is not that much about the development of innovations “turnkey” or “ready-mix” solutions. The real challenge is to provide components and basic tools to be mobilized within the innovation process and put in place economic operators based on systems characteristics. This will allow major actors and their strategies to effectively operate at local conditions. Participatory approach involving all actors of the food chain (from upstream to downstream level) may allow to develop sustainable pest management strategies while enhancing and/or maintaining the productivity of our agricultural systems.

2. Integrated Pest Management for sustainable crop protection

Historically, the concept of Integrated Pest Management (IPM) gained international visibility following catastrophic pest outbreaks leading to severe yield losses. An example is brown rice leafhopper outbreaks occurred in Indonesia in the 1970s, soon after the cultivation of high yielding cultivars coupled with intensive use of fertilizers and insecticides (Siwi and Roechan, 1983). Subsequently, “the systems approach” based on the banning of broad-spectrum insecticides, the selection of resistant varieties and the training of farmers on IPM, with the support of FAO, were effective to address the problem (Kogan, 1998).

More specifically to IPM in Europe, the European Union (EU) is moving towards a sustainable agriculture with the current transition from conventional crop protection system to IPM (Lamichhane et al., 2016b). The implementation of the eight IPM principles (Barzman et al., 2015), mandated by the Directive 128/2009/EC, is a historic opportunity to renovate the innovation system of European agriculture. However, there are still challenges related to IPM adoption which need to be addressed through a joint effort that encourages interdisciplinary research and networking across borders (Lamichhane et al., 2016a).

Overall, EU policy is directed towards significant reductions in pesticide use in the short to medium term which already has resulted in the loss from the EU market of some important pesticides (Hillocks, 2012). Therefore, research and policy have to encourage the development of non-chemical tools for pest management, their integration into the IPM toolbox and effective adoption. This will help address farmers' need to protect their crops in a more sustainable way. Food security can be challenged by a rapid build-up and spread of pests and IPM represents a valid alternative to conventional crop protection systems while it comes to the need of ensuring crop yield and productivity, on one hand, and the sustainability of our agricultural systems, on the other. IPM envisages the adoption of non-chemical tools wherever possible but, at the same time, also allows to use less toxic pesticides respecting the IPM principles (Barzman et al., 2015). So a set of IPM tools are already available and it is up to the stakeholders (*sensu lato*) to make their better combination and use possible taking into account both biotic and abiotic factors that directly or indirectly affect the occurrence and spread of pests across cropping systems. Therefore, our focus should be on: how can we improve the IPM system, how can we enhance its adoption on a global scale, how can we insert and combine all non-chemical tools into the IPM toolbox to strengthen this system and reduce the reliance on conventional pesticides.

3. Introduction to the special issue: pesticide use and risk reduction in european farming systems with Integrated Pest Management

In light of the current transition that the EU agriculture faces, the European Commission has intensified its effort toward the development of more sustainable tools and knowledge to be integrated into the IPM toolbox. The EU project PURE (Pesticide Use-and-risk Reduction in European farming systems with Integrated Pest Management; http://www.pure-ipm.eu) was a telling example in this regard (Lescourret, 2014). PURE was the first EU-funded IPM project which clearly emphasized the need of innovation in crop protection involving a large number of stakeholders. Within its four-year funded period (2011–2015), PURE has designed, tested and assessed innovative solutions in a wide range of cropping systems including annual (wheat, maize, field vegetables, and ‘protected’ vegetables grown under poly-tunnels) and perennial (pome fruits and grapevines) crops. Taking into account regional and site-specific environmental conditions across different European regions and/or contexts, PURE markedly contributed to address various facets of sustainability of IPM (see Lescourret, 2016).

The approach used for the development and adoption of innovative IPM tools and/or methods within the project PURE and results obtained therein are described in this special issue that gathers 16 papers, including 1 introducing the project PURE, 12 original and 3 review articles. The articles are classified into four sections: i) models and methods to help design and assess IPM strategies, ii) design and assessment of IPM strategies in European cropping systems, iii) biological and technological tools for IPM, and iv) ecological engineering for IPM. The papers in this issue show that progress is being made for the development of innovative crop protection systems that allow to reduce pesticide use and risk in European farming systems. The following are representative short summaries of the articles that appear in this issue.

3.1. Models and methods to help design and assess IPM strategies

Host plant resistance is the most important component of IPM for environmental, economic, and social reasons. Therefore, appropriate plant resistance deployment strategies are relevant for durable resistance, especially taking into account scarcity of resistant genes in the context of major global challenges. Therefore, it is pivotal to identify and deploy strategies that can prolong the useful life of plant resistance genes. Lof and van der Werf (2016) compare *in silico* three basic strategies of deployment, including gene stacking (or pyramiding), sequential use, and simultaneous use, both individually and in combinations. The authors demonstrate that, unlike what is generally thought, pyramiding is not always the most durable strategy and that the latter depends on the threshold fraction at which resistance breakdown occurs. At the same time, the threshold fraction is affected by the economic value of the crop and the level of acceptance of damage on a given crop. Overall, the authors show that gene pyramiding is the most durable solution when the threshold is low while in other cases simultaneous use of single-gene resistant varieties improves durability of resistance.

The development of any tool that aims at assessing sustainable cropping systems must consider the economic, social and environmental dimensions of sustainability. While a number of