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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

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sustainability assessment tools have been developed and used to meet this requirement, all of them have a common drawback, meaning that they handle a single type of production system (either arable, fruits or vegetables) and at a specific stage (either *ex-ante* or *ex-post* assessments). To address the common limit of previous studies, Angevin et al. (2016) propose a common framework for sustainability assessment that can be used in various assessment situations. The authors developed a single tool that addresses all type of production systems and by adapting the already existing DEXiPM model, previously designed for the *ex-ante* assessment of innovative arable crop systems. Such a common framework has the potential to facilitate both development and adoption of innovative cropping systems.

In many European countries, pesticide use is often measured with an indicator called treatment frequency index. However, the key limit of this indicator is that, while it measures the number of pesticide applications, it does not take into account the differences in inherent toxicological properties of pesticides. This means that this indicator cannot be used as a tool to measure risks arising from the use of pesticides. To address this limit, Strassemeyer et al. (2017) introduce SYNOPS-WEB, an easy-to-use environmental risk assessment tool, which assesses both acute and chronic risks of pesticides to soil, surface water and pollinators, as well as via leaching to groundwater. This tool is expected to provide realistic output to European stakeholders in developing and optimizing IPM strategies that focus on reducing risks arising from the use of conventional pesticides.

3.2. Design and assessment of IPM strategies in european cropping systems

3.2.1. Annual cropping systems

One of the major drawbacks of conventional insecticides is their harmful effect on non-target organisms. This often leads to a high mortality of natural enemies of harmful pests thereby creating imbalance in natural pest regulation systems. Therefore, it is imperative that any sustainable crop protection practice carefully considers the choice of appropriate insecticides which can reduce their effects on non-target organism at a minimum level. Vasileiadis et al. (2016a) demonstrate how a careful choice of insecticides can lead to an effective management of the European corn borer *Ostrinia nubilalis*, in maize within the frame of IPM, without any negative effects on the minute pirate bug (*Orius* spp.). The latter is a beneficial organism which was considered as the indicator species to evaluate the impact of the three crop protection strategies adopted in maize.

Numerous conventional insecticides are applied annually into the agricultural soils to manage soil pests. Such chemicals are often used as a routine, rather than based on a real need, frequently without a proper assessment about the threat posed by soil pests or without determining the economic threshold. This consists of a high cost for farmers, on one hand, and for the environment, on the other, including contamination of groundwater or soil accumulation of insecticides which affect crop health in the long term. Probably the most important effect of these insecticides can be seen through toxicity to soil biota which plays an important role in the soil food web. Therefore, it is essential that conventional insecticides are used only when there are high risks of yield losses and based on the precise determination of the economic threshold. Furlan et al. (2016) determine risk of damage to maize due to wireworms, the most economically important soil pest of this crop, in Europe and show that overall there is a low risk of wireworm damage to maize in many European countries which does not justify the frequently used application of insecticides.

Due to a high biotic pressure, arable crops still widely rely on conventional pesticides. In addition, because they are destined either for processed food or feed, these crops have drawn less attention by consumers, in terms of pesticide residues compared to freshly consumed products such as fruit and vegetables. Nevertheless, there is a tremendous need to reduce the use of conventional pesticides in these crops by adopting more sustainable crop protection strategies. This is especially true taking into account the number of hectares grown to arable crops which is far higher than that grown to other crops. Thus only a moderate reduction in the use of conventional pesticides in arable crops may result in significant gains, in terms of human health and the environment. The development of effective and sustainable crop protection strategies is however a challenging task due to very different environmental conditions across Europe. Vasileiadis et al. (2016b) evaluate the economic, environmental and social sustainability of conventional and two levels of IPM-based crop protection practices in European winter wheat- and maize-based cropping systems using the modified DEXiPM for *ex-post* assessment. The authors show that, while most conventional crop protection practices assessed were not sustainable, IPM systems — based on lower pesticide use, integration of non-chemical tools and diversified crop rotations — did show an overall sustainability. The adoption of IPM practices thus offers a valid potential to reduce reliance on conventional pesticides in arable crops.

3.2.2. Grapevine

Conventionally grown grapevine is one of the perennial crops with the highest reliance on conventional pesticides. Many problems related to human health, especially in Western Europe, have been associated with the intense use of conventional pesticides in grapevine. Consequently, grapevine farmers increasingly attempted to adopt non-chemical crop protection tools. Grapevine is probably one of the crops benefitting from the largest number of such tools combined and applied within the IPM framework. This also in part thanks to organic farmers who, since a long time, have learnt to adapt all available non-chemical measures to their local and site-specific conditions. Pertot et al. (2016) review IPM tools available for farmers to protect grapevine and highlight both their benefits and limits. The authors conclude that the ongoing IPM trend in grapevine is positive and that IPM has a good potential to reduce reliance on conventional pesticides.

The efficacy of biocontrol agents/methods is often considered as too limited or variable. This is mainly due to two reasons: i) their application at non-optimal growth stage of plants, which hinders their colonization potential, and ii) because most biocontrol methods/agents have only partial effects in managing pests, their individual application does not allow to fully contain pest populations. Pertot et al. (2017) investigate the potentiality of three biocontrol agents — namely *Trichoderma atroviride, Aureobasidium pullulans* and *Bacillus subtilis* — in managing *Botrytis cinerea* on grapevine, either individually or in combination at several growth stages of the plant. Through multiyear trials performed across different areas of Northern Italy, the authors demonstrate that *T. atroviride, A. pullulans* and *B. subtilis*, applied at bunch-closure, veraison and pre-harvest, respectively, either individually or in combination effectively contain *B. cinerea* populations on bunches.

3.2.3. Horticulture

Two major challenges characterize the transition phase from conventional crop protection system to IPM. The first regards the development of non-chemical tools which can be integrated into the IPM toolbox and made available to farmers while the second is their adoption by farmers. While a lot of efforts from research and policy, especially in Europe, allowed to develop IPM tools and put them at farmers' disposal, their adoption is not always the case. This

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clearly highlights that the supply of knowledge and new technologies alone is not enough for their adoption by farmers but rather the motivations of the latter and the support of their value chain partners mainly play an important role in adoption of new IPM solutions. This clearly suggests the need to embrace a multidisciplinary approach to bridge the current R&I gap in crop protection. Taking these factors into account, Buurma and van der Velden (2016) offer a way of planning and developing IPM R&I which can be aligned to the needs of farmers to ensure the development of technologies, readily adoptable in practice by farmers. The authors do this taking an example of horticulture in general and greenhouse tomato production chain in particular.

3.2.3.1. Pomefruit systems. Pomefruit systems represent one of the major crop species which still heavily rely on conventional pesticides. Development and testing of innovative crop protection tools and methods are thus a priority for research to provide sustainable crop protection tools for pomefruit farmers. Even more important is the fact that, often, such innovative IPM tools are available but they are not transferred to growers' practice and/or adopted by them on a large scale due to socio-economic constraints. Caffi et al. (2016) develop a multi-criteria evaluation and assess the advantages and disadvantages of adopting innovative IPM strategies to manage major pomefruit pests, compared to the standard IPM practice. The authors assess environmental risks, economic effects and sustainability impact for all innovative strategies tested. Overall, the authors, based on the multi-criteria assessment, demonstrate that there is a good potentiality for an improved environmental quality based on innovative IPM systems.

Apple scab and powdery mildew are the most economically important fungal diseases of apple worldwide and which together represent over 50% of crop protection input dedicated to apple. The number of fungicide sprays against the two diseases ranges between 12 and 25 annually depending on a number of factors including seasonal weather conditions, cultivar susceptibility, crop management systems, and growing regions. Therefore, there is a need to develop and adopt crop protection strategies which could be less reliant on conventional fungicides, on one hand, and economically sustainable for farmers, on the other. In light of this, Holb et al. (2016) performed on-farm and on-station evaluations of conventional, standard and advanced IPM systems. The authors demonstrate that there is a potential to reduce reliance on conventional fungicides through standard IPM system without compromising yield and fruit quality.

3.2.3.2. Protected horticulture. Protected horticulture is one of the most important sectors in terms of economics. Because high value crops are grown in this system, farmers often seek innovative and sustainable pest management tools to ensure high quality and blemish-free products as demanded by the consumers. Consequently, research has widely focused to develop a set of innovative IPM tools which have been also widely adopted in protected horticulture. More specifically to invasive pests, there have been numerous historical events during which the economic viability of protected horticulture was challenged. A recent example regards the invasion of *Tuta absoluta* in greenhouse tomato. Pérez-Hedo et al. (2016) review this aspect showing how research has provided effective and sustainable IPM tools to manage *T. absoluta* on tomato in protected horticulture in Europe. The authors highlight how application of a Miridae as a zoophytophagous predator of the pest and *Trichoderma* spp. allowed to manage this pest activating direct and indirect plant defence responses and finally increasing resilience and robustness of the crop.

3.3. Biological and technological tools for IPM

Conventional pesticides have come under increasing scrutiny in recent years due to their adverse effects on human health and the environments. This has led to a number of legislations which aim at forbidding or limiting the use of conventional pesticides, especially in the EU. A large number of previously used conventional pesticides are not anymore available on the EU market. This scenario has created a demand from farmers for alternative means to protect their crops and thus research has an important role to play to fulfill this demand and try to develop alternatives to conventional pesticides at the same pace as pesticides are currently being restricted. Bruce et al. (2016) evaluate potentials of some plant defense activators, plant extract and biocontrol agent in IPM to manage a number of economically important pests of tomato. Their results suggest that these non-chemical tools have a good crop protection potential, especially when they are combined with other IPM strategies. The authors however highlight that such tools are more complicated to deploy and that their effectiveness varies depending on specific situations of their deployment.

Screening for new biocontrol agents suitable for commercial use is an important approach to enlarge the range of biocontrol solutions available for farmers. Once a number of potential biocontrol agents have been selected through screening, the second step would be to develop adequate production and formulation processes for biocontrol agents both to reduce costs related to their production and improve their efficacy. Angeli et al. (2016) adopt this approach in order to improve the production of conidia of *Ampelomyces quisqualis*, a new fungal isolate which acts as an antagonist against powdery mildew, one of the most important fungal pathogens. The authors test submerged fermentation method to produce conidia of *A. quisqualis* and reports an optimal nutrient composition and growth conditions for high mycelial growth and conidiation of the antagonist fungal strain. The method they propose and the medium they propose are cost-effective and allow to have a stable and effective dry formulation for the conidia.

3.4. Ecological engineering for IPM

Conservation biocontrol is one of the most important and sustainable pest regulation strategies, especially when combined with other IPM tactics. However, the effectiveness of conservation biocontrol in fostering indigenous natural enemies and contributing to suppression of pests varies, sometimes even resulting in its failure. This is the main obstacle that often hinders adoption of conservation biocontrol in commercial crop production settings which is mainly due to the very complex nature of conservation biocontrol and important knowledge gaps about the underlying factors. To address this issue, Begg et al. (2016) review and propose a unifying framework based on the organization of the functional elements of conservation biocontrol. They do this by consolidating existing knowledge on conservation biocontrol via a simple conceptual model. The authors identify and integrate the key biological processes affecting the natural enemies and their biocontrol function, and consider the interactions, interdependencies and constraints that determine the outcome of CBC strategies. Such an approach is supposed to help overcome obstacles related to the adoption of conservation biocontrol.

4. What future for IPM?

It is certain that the future of IPM will depend on a flow of innovations besides those that come under agrochemicals, as shown by a number of research works presented in this issue. Therefore we should examine what may be the nature of these innovations,

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how they are constructed, how they can be organized into coherent strategies and get into the practice of farmers and finally what is the contribution of the different actors of socio-economic system to innovation process to make IPM successful. IPM solutions promptly applicable into practice can be developed only if we focus on co-innovation of agriculture based on a multi-stakeholder perspective. Any effort from research and policy thus should encourage the involvement of actors that represent the entire food chain. More specifically to Europe, we still need to: i) go beyond the traditional top-down or bottom-up approaches of organizing research and need to adopt participatory research approach, based on an enhanced involvement of farmers, ii) develop more sustainable IPM solutions promptly adaptable/applicable into practice, iii) focus on long-term experiments that allow to generate reliable data on the durability and sustainability of IPM systems, iv) put in place more collaborative research based on public-private partnership, and v) invest more on the advisory services to help farmers shift from conventional crop protection system into IPM.

The future of IPM will be challenging since we have an increasing need today to develop sustainable IPM tools, possibly the non-chemical ones, and ensure their adoption by farmers to promote durable and sustainable agriculture. Pest resistance development to pesticides will be a real challenge in the future as the reliance on fewer active ingredients, especially in Europe, is likely related with the consequent greater risk of pesticide resistance in the target pests. Numerous works in this issue have demonstrated that, IPM in general and the advanced IPM system in particular can markedly reduce reliance on conventional pesticides. Policy frameworks are thus invited to take this fact into account and put in place measures that allow an effective adoption of IPM. This will ensure sustainable food production in Europe at current levels and addressing, at the same time, human health and environmental issues. A proper attention to the social environment in which farmers operate collective learning and farmer's inclination for step-wise rather than drastic changes will certainly help promote IPM adoption in Europe.

Transitions into an IPM system less reliant on pesticide use need a wide innovation effort which is not just a matter of stimulating technical innovation flows. This transition to new forms of crop protection implies a change in the nature of these innovations. The result is a need for new approaches, devices, methods and tools that leads to rethink the entire system of innovation (Ricci et al., 2011). To this aim, networking in IPM R&I at regional, national or trans-national level is essential to optimize human and economic resources devoted to develop IPM tools and to increase their adoption by farmers (Lamichhane et al., 2016a). The efforts made within the European project PURE and results presented in this issue are a telling example of how such a networking approach can produce reliable scientific and technical data useful to support policy frameworks.

Finally, the current cropping systems are designed in a way whereby conventional pesticides are an integral part of the protection systems. Therefore, we have to re-design our cropping systems which could be less-intensive and more resilient to biotic stresses thereby allowing to reduce reliance on conventional pesticides (Lechenet et al., 2014). At the field or farm scale, the nature and amount of pesticides used are mainly crop-dependent since each crop or vegetative cover faces a specific complex of associated pests. As shown by several works in this issue, major crops, such as apple or grapevine, receive dozens of applications per year. Therefore, changes in pesticide use over time is possible either through land use changes (i.e. from the substitution of crops receiving contrasting levels of pesticides per hectare) or from changes in pesticide use intensity (i.e. reduction in application rates per hectare for a given crop adopting advanced IPM) (Urruty et al., 2016). A better focus on crop diversification will result in important benefits in terms of reduced reliance on conventional pesticides. However, also here, appropriate public policy frameworks should concomitantly be developed to overcome potential technical and organizational barriers along the food production and supply chain systems that may hamper the adoption of crop diversification practices.

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References

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19–31.

Altieri, M., Rogé, P., 2010. The ecological role and enhacement of biodiversity in agriculture. In: Lockie, S., Carpenter, D. (Eds.), Agriculture, Biodiversity and Markets. Earthscan. Earthscan, London, UK, pp. 15–32.

Angeli, D., Saharan, K., Segarra, G., Sicher, C., Pertot, I., 2016. Production of *Ampelomyces quisqualis* conidia in submerged fermentation and improvements in the formulation for increased shelf-life. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.012.

Angevin, F., Fortino, G., Bockstaller, C., Pelzer, E., Messéan, A., 2016. Assessing the sustainability of crop production systems: toward a common framework? Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.018.

Bale, J.S., van Lenteren, J.C., Bigler, F., 2008. Biological control and sustainable food production. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 363, 761–776.

Barzman, M., Bàrberi, P., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., 2015. Eight principles of integrated pest management. Agron. Sustain. Dev. 35, 1199–1215.

Begg, G.S., Cook, S.M., Dye, R., Ferrante, M., Franck, P., Lavigne, C., Lövei, G.L., Mansion-Vaquie, A., Pell, J.K., Petit, S., Quesada, N., Ricci, B., Wratten, S.D., Birch, A.N.E., 2016. A functional overview of conservation biological control. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.008.

Birch, A.N.E., Begg, G.S., Squire, G.R., 2011. How agro-ecological research helps to address food security issues under new IPM and pesticide reduction policies for global crop production systems. J. Exp. Bot. 62, 3251–3261.

Bruce, T.J.A., Smart, L.E., Birch, A.N.E., Blok, V.C., MacKenzie, K., Guerrieri, E., Cascone, P., Luna, E., Ton, J., 2016. Prospects for plant defence activators and biocontrol in IPM – concepts and lessons learnt so far. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.10.003.

Buurma, J.S., van der Velden, N.J.A., 2016. New approach to Integrated Pest Management research with and for horticulture. A vision from and beyond economics. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.013.

Caffi, T., Helsen, H.H.M., Rossi, V., Holb, I.J., Strassemeyer, J., Buurma, J.S., Capowiez, Y., Simon, S., Alaphilippe, A., 2016. Multicriteria evaluation of innovative IPM systems in pome fruit in Europe. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.12.009.

DeFries, R., Rosenzweig, C., 2010. Toward a whole-landscape approach for sustainable land use in the tropics. Proc. Natl. Acad. Sci. U. S. A. 107, 19627–19632. http://dx.doi.org/10.1073/pnas.1011163107.

Furlan, L., Vasileiadis, V.P., Chiarini, F., Huiting, H., Leskovšek, R., Razinger, J., Holb, I.J., Sartori, E., Urek, G., Verschwele, A., Benvegnù, I., Sattin, M., 2016. Risk assessment of soil-pest damage to grain maize in Europe within the framework of integrated pest Management. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.029.

Hillocks, R.J., 2012. Farming with fewer pesticides: EU pesticide review and resulting challenges for UK agriculture. Crop Prot. 31, 85–93.

Holb, I.J., Abonyi, F., Buurma, J., Heijne, B., 2016. On-farm and on-station evaluations of three orchard management approaches against apple scab and apple powdery mildew. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.023.

Kogan, M., 1998. Integrated pest management: historical perspectives and contemporary developments. Annu. Rev. Entomol. 43, 243–270.

Lamichhane, J.R., Aubertot, J.-N., Begg, G., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Hansen, J.G., Al, E., 2016a. Networking of Integrated Pest Management: a powerful approach to address common challenges in agriculture. Crop Prot. 89, 139–151.

Lamichhane, J.R., Bischoff-Schaefer, M., Bluemel, S., Dachbrodt-Saaydeh, S., Dreux, L., Jansen, J.-P., Kiss, J., Köhl, J., Kudsk, P., Malausa, T., Messéan, A., Nicot, P.C., Ricci, P., Thibierge, J., Villeneuve, F., 2017. Identifying obstacles and ranking common biological control research priorities for Europe to manage most economically important pests in arable, vegetable and perennial crops. Pest Manag. Sci. 73, 14–21. http://dx.doi.org/10.1002/ps.4423.

Lamichhane, J.R., Dachbrodt-Saaydeh, S., Kudsk, P., Messéan, A., 2016b. Toward a reduced reliance on conventional pesticides in European agriculture. Plant Dis. 100, 10–24. http://dx.doi.org/10.1094/PDIS-05-15-0574-FE.

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Lechenet, M., Bretagnolle, V., Bockstaller, C., Boissinot, F., Petit, M.S., Petit, S., Munier-Jolain, N.M., 2014. Reconciling pesticide reduction with economic and environmental sustainability in arable farming. PLoS One 9.

Lechenet, M., Deytieux, V., Antichi, C., Aubertotd, J.-N., Bàrberi, P., Bertrand, M., et al., 2016. Diversity of methodologies to experiment Integrated Pest Management in arable cropping systems: analysis and reflections based on a European network. Eur. J. Agron.

Lescourret, F., 2016. Toward a reduced use of pesticides in European farming systems: an introduction to the PURE project. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.12.004.

Lescourret, F., 2014. IPM and the integration of innovative application techniques in IPM. Asp. Appl. Biol. 122, 153–157.

Lescourret, F., Poncet, C., Simon, S., 2016. Insights into the ecological control of pests in horticulture. In: Acta Horticulturae. International Society for Horticultural Science (ISHS), Leuven, Belgium, pp. 91–104. http://dx.doi.org/10.17660/ActaHortic.2016.1137.14.

Lichtfouse, E., Navarrete, M., Debaeke, P., Souchère, V., Alberola, C., Ménassieu, J., 2009. Agronomy for sustainable agriculture: a review. In: Sustainable Agriculture. Springer, Netherlands, pp. 1–7.

Lof, M.E., van der Werf, W., 2016. Modelling the effect of gene deployment strategies on durability of plant resistance under selection. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.031.

Lucas, J.A., 2011. Advances in plant disease and pest management. J. Agric. Sci. 149, 91–114.

Mahlein, A.-K., 2016. Plant disease detection by imaging sensors – parallels and specific demands for precision agriculture and plant phenotyping. Plant Dis. 100, 241–251.

Meynard, J.M., 2008. Produire autrement ;: réinventer les systèmes de culture. In: Reau, R., Doré, T. (Eds.), Des Systèmes de Culture Innovants et Durables ;: Quelles Méthodes Pour Les Mettre Au Point et Les Évaluer? Educagri, pp. 11–27.

Oerke, E.C., 2006. Crop losses to pests. J. Agric. Sci. 144, 31–43. http://dx.doi.org/10.1017/S0021859605005708.

Pérez-Hedo, M., Suay, R., Alonso, M., Ruocco, M., Giorgini, M., Poncet, C., Urbaneja, A., 2016. Resilience and robustness of IPM in protected horticulture in the face of potential invasive pests. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.001.

Pertot, I., Caffi, T., Rossi, V., Mugnai, L., Hoffmann, C., Grando, M.S., Gary, C., Lafond, D., Duso, C., Thiery, D., Mazzoni, V., Anfora, G., 2016. A critical review of plant protection tools for reducing pesticide use on grapevine and new perspectives for the implementation of IPM in viticulture. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.025.

Pertot, I., Giovannini, O., Benanchi, M., Caffi, T., Rossi, V., Mugnai, L., 2017. Combining biocontrol agents with different mechanisms of action in a strategy to control *Botrytis cinerea* on the grapevine. Crop Prot. (In press).

Ricci, P., Bui, S., Lamine, C., 2011. Repenser la protection des cultures ;: innovations et transitions. In: Educagri (Ed.), Quae. ISBN: 978-2-7592-1676-5.

Savary, S., Horgan, F., Willocquet, L., Heong, K.L., 2012. A review of principles for sustainable pest management in rice. Crop Prot. 32, 54–63.

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., van Oosten, C., Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. U. S. A. 110, 8349–8356. http://dx.doi.org/10.1073/pnas.1210595110.

Siwi, S.S., Roechan, M., 1983. Species composition and distribution of green rice leatlaopper, Nephotettix spp. and spread of tungro virus disease in Indonesia. In: 1st International Workshop on Leaf and Planthoppers of Economic Importance, pp. 263–276.

Strassemeyer, J., Daehmlow, D., Dominic, A.R., Lorenz, S., Golla, B., 2017. SYNOPS-WEB, an online tool for environmental risk assessment to evaluate pesticide strategies on field level. Crop Prot. 1–17. http://dx.doi.org/10.1016/j.cropro.2016.11.036.

Urruty, N., Deveaud, T., Guyomard, H., Boiffin, J., 2016. Impacts of agricultural land use changes on pesticide use in French agriculture. Eur. J. Agron. 80, 113–123. http://dx.doi.org/10.1016/j.eja.2016.07.004.

Vasileiadis, V.P., Veres, A., Loddo, D., Masin, R., Sattin, M., Furlan, L., 2016a. Careful choice of insecticides in integrated pest management strategies against *Ostrinia nubilalis* (Hübner) in maize conserves Orius spp. in the field. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.003.

Vasileiadis, V.P., Dachbrodt-Saaydeh, S., Kudsk, P., Colnenne-David, C., Leprince, F., Holb, I.J., Kierzek, R., Furlan, L., Loddo, D., Melander, B., Jørgensen, L.N., Newton, A.C., Toque, C., van Dijk, W., Lefebvre, M., Benezit, M., Sattin, M., 2016b. Sustainability of European winter wheat- and maize-based cropping systems: economic, environmental and social ex-post assessment of conventional and IPM-based systems. Crop Prot. http://dx.doi.org/10.1016/j.cropro.2016.11.002.

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