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Sustainability of European winter wheat- and maize-based cropping systems: Economic, environmental and social *ex-post* assessment of conventional and IPM-based systems

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ABSTRACT

In order to ensure higher sustainability of winter wheat and maize production in Europe, cropping systems featuring different levels of Integrated Pest Management (IPM) need to be tested in the field and validated for their sustainability before being adopted by farmers. However, the sustainability evaluation of cropping systems is difficult to perform effectively due to the complex economic, social and environmental dimensions of sustainability. Within the EU research project PURE, nine long-term experiments were conducted in various European regions from 2011 to 2014, comparing two IPM levels against the conventional system (CS) in winter wheat- and maize-based cropping systems. IPM1 encompassed some pesticide use in semi-diverse crop rotations while IPM2 favoured reduced- and non-chemical methods in diverse rotations. The modified DEXiPM (DEXi Pest Management) model for arable cropping systems was used for *ex-post* assessments to compare the economic, environmental and social sustainability of these systems. The assessments showed that in six out of nine trials the CS was overall unsustainable because of low evaluation of the environmental sustainability that was mainly due to high pesticide use and simplified crop rotations where the choice of crops is primarily market-driven. In contrast, six IPM1 and five IPM2 systems could be classified as sustainable, achieving 'medium' or 'high' scores for all three sustainability dimensions. Differences in the socio-economic conditions across countries and/or climatic and soil conditions across experimental trials highlighted that IPM is based on general principles that must be adapted to address specific local conditions. Overall, IPM systems included more diverse crop rotations and practices compared to the CS, promoting IPM-based strategies with less pesticide use but also a reduced reliance on pesticides that could partially compensate for any yield reductions by the savings on pesticide and application costs. It is recommended that the results of the study should be disseminated to policy-makers, advisors and farmers and that their implementation should be considered on a regional level. Regional policies to encourage the adoption of more sustainable systems based on IPM principles, as well as better support by more closely involving the regional advisory services for the general implementation of IPM is further recommended. *Ex-post* analysis with

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DEXiPM also identified the constraints of the IPM1 and IPM2 systems evaluated as not sustainable. These were related to i) environmental issues for those IPM1 systems that still relied mainly on pesticide use and had less diverse crop rotations, and ii) economic issues for IPM2 systems, mainly due to the choice of less profitable crops in the rotation, as well as to yield penalties caused by the very low pesticide use or replacing pesticides with less effective non-chemical methods. The identification of these constraints is a valuable input to the local and regional discussion on how to adopt IPM and develop more sustainable cropping systems.

1. Introduction

During the last 50 years in Europe, agricultural production has intensified and yields have increased significantly due to the availability of high-yielding crop varieties, synthetic fertilizers and the intensive use of chemical pesticides that achieve better pest control (Meissle et al., 2010). Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are among the most important crops in the European Union (EU) member states, covering a production area of approximately 27 and 16 million hectares in 2014, respectively (EUROSTAT, 2016). Wheat and grain maize are intensively grown for food and feed, whereas green maize is used for silage or biogas production. Mineral N fertiliser inputs in wheat and maize cropping systems are high to ensure appreciable yields (Meissle et al., 2010; Hawkesford, 2014). Weeds and diseases are major constraints for wheat production, influencing both yield and grain quality (Oerke, 2006). Since the introduction of triazole fungicides in the 1980s, fungicide use has become common practice especially in winter wheat (Jørgensen et al., 2014), together with a high herbicide input. Recent studies on European maize have also indicated that crop protection is mainly pesticide-based with high herbicide inputs. More than 90% of the total maize growing area in 11 European regions, as classified and studied by Meissle et al. (2010) and Vasileiadis et al. (2011, 2013, 2015), has been reported to be treated with herbicides at least once in the growing season.

The long-term sustainability and environmental impacts of increased pesticide use in winter wheat- and maize-based cropping systems have raised concerns about adverse effects on human and animal health, environmental pollution (water and soil), and effects on beneficial organisms like pollinators, decomposers and natural enemies of pests (Pimentel, 2005; Meissle et al., 2010). The most recent political initiatives by the European Commission indicate a clear will to increase the sustainability of cropping systems (Lamichhane et al., 2016). The Directive on the Sustainable Use of Pesticides (European Parliament, 2009) that urges all Member States to adopt the general principles of IPM and the so-called 'greening' of the Common Agricultural Policy are two examples of EU policies aiming at reducing pesticide risks whilst ensuring economic profitability, environmental safety and social sustainability in European cropping systems (Vasileiadis et al., 2013). To properly develop sustainable cropping systems, the type of cropping sequence, crops in the sequence and crop protection practices against all important pests, weeds and diseases in the system should be considered (Lechenet et al., 2016). Hence, IPM-based cropping systems need to be designed, tested and validated to meet the demand for food safety and security, lower environmental impacts and economic sustainability (Bohanec et al., 2008). Nevertheless, evaluating the sustainability of such cropping systems is a complex task due to the conflicting objectives underlying the economic, environmental and social dimensions of sustainability (Sadok et al., 2008).

Multi-criteria decision-aid methods have been developed and applied to assess agricultural sustainability (e.g., Bohanec et al., 2008; Sadok et al., 2009; Pavlovic et al., 2011). DEXiPM® (DEXi Pest Management; Pelzer et al., 2012) was developed recently within the EU Network of Excellence ENDURE (European Network for Durable Exploitation of Crop Protection Strategies; http://www.endure-network.eu) with the aim of performing *ex-ante* assessment of the sustainability of innovative IPM-based arable cropping systems. DEXiPM is an appropriate tool to evaluate all aspects of the sustainability of existing cropping systems, diagnose their strengths and weaknesses, and encourage discussions during the design of innovative cropping systems to be tested in fields (Vasileiadis et al., 2013). Within the EU research project PURE (Pesticide Use and risk Reduction in European farming systems with integrated pest management; http://www.pure-ipm.eu) (Lescourret, 2014), a major work package was devoted to winter wheat-based cropping systems and another to maize-based cropping systems. During the four years of the project, two IPM levels were tested in long-term on-station experimentation under field conditions against the conventional management followed in the most common rotations. The need for validating the sustainability of the various cropping systems led to the development of a DEXiPM *ex-post* version adapting the original model to be used for *ex-post* assessment (see Angevin et al. in this issue). Thus, the objectives of this study were to (i) assess *ex-post* the economic, environmental and social sustainability of conventional winter wheat- and maize-based cropping systems and of IPM-based systems designed and tested in nine locations in Europe and (ii) compare their sustainability, discussing the benefits or drawbacks of the IPM systems.

2. Materials and methods

2.1. Adapting DEXiPM for ex-post assessment

DEXiPM, a hierarchical and entirely qualitative multi-criteria decision-aid model based on DEXi software (Bohanec, 2009), was originally developed to assess *ex-ante* the overall sustainability of cropping systems decomposing it into less complex items, starting from the three dimensions of sustainability: environmental, economic and social. Detailed information on the model design (choice and hierarchy of basic and aggregated indicators, choice of qualitative states for indicators, utility functions/aggregation rules determining the aggregation of indicators on the tree and their relative weight) is given in Pelzer et al. (2012).

In the *ex-post* version developed within the PURE project, DEXiPM uses a different type of data depending on the availability of field records and quantitative assessments rather than using qualitative data as in the *ex-ante* version. The indicators that are measurable or could be quantitatively estimated with models were adapted and included accordingly in the *ex-post* version. These included economic indicators that could be measured or calculated, i.e. "yield", "production value", "cost of pesticides", "gross margin", and some environmental indicators, i.e. the risk potential for terrestrial (soil and field margin biotopes) and aquatic (surface

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