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On-farm evaluation of integrated weed management tools for maize production in three different agro-environments in Europe: Agronomic efficacy, herbicide use reduction, and economic sustainability

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ABSTRACT

The development and implementation of integrated weed management (IWM) strategies that provide good weed control while reducing dependence on herbicides, and preferably without having side effects on the overall system economic performance, is still a challenge that has to be met. In 2011 and 2012, nine on-farm experiments (i.e., real field conditions on commercial farms, with natural weed flora) were conducted in three important European maize producing regions-countries, which represent the range of climatic and edaphic conditions in Europe, to evaluate the efficacy of different locally selected IWM tools for direct weed control in maize vs. the conventional approach (CON) followed by the farms. The IWM tools tested were: (1) early post-emergence herbicide band application combined with hoeing followed by a second hoeing in Southern Germany, (2) early post-emergence herbicide broadcast application when indicated by a predictive model of weed emergence after performing one scouting in the field to supply data for the model, followed by hoeing in Northern Italy, and (3) tine harrowing at 2–3rd leaf stage of maize and low dose of post-emergence herbicide in Slovenia. Results showed that the IWM tools tested in the different countries: (1) provided sufficient weed control without any significant differences in yields, (2) greatly reduced maize reliance on herbicides, and (3) IWM implementation was economically sustainable as no significant differences in gross margin were observed in any country compared to CON.

1. Introduction

For more than 50 years, herbicides have been the primary tool for weed control worldwide (Ghersa et al., 2000; Liphadzi and Dille, 2006). This has been very effective in all major crops, greatly reducing yield losses and stabilizing potential weed infestations at acceptable levels (Chikowo et al., 2009). Nevertheless, in most arable crops, the dependence on herbicides is a key societal issue as their use is increasing worldwide (Gianessi, 2013), contaminating the surface and below-ground waters in Europe (Croll, 1991; Haarstad and Ludvigsen, 2007), in the United States (Holman et al., 2000) and wherever intensive farming systems prevail. Despite the rising awareness related to high herbicide inputs, farmers are still reluctant to adopt alternative weed control measures due to increased cropping system complexity and higher perceived agronomic and economic risks (Deytieux et al., 2012).

Maize (*Zea mays* L.) is one of the most important crops in Europe, covering a production area of approximately, 14 million hectares in 2012 (excluding the ex-Soviet Union republics; FAOSTAT, 2013) and is cultivated as grain for food, feed and processing, and as green maize for silage or biogas production. Recent studies on European maize have indicated that crop protection is mainly pesticide-based, with high herbicide inputs, as more than 90% of the total maize crop area in 11 European regions has been reported

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to be treated with herbicides (Meissle et al., 2010; Pelzer et al., 2012; Vasileiadis et al., 2011, 2013) at least once in a season. This dependence on herbicides stems from the fact that maize is rather sensitive to early competition (Cerrudo et al., 2012) and is often infested by weeds that are highly competitive (Sattin et al., 1992). Weeds are therefore a major problem worldwide especially in continuous maize systems, and their management is vital for achieving optimum yield of high quality product (Rajcan and Swanton, 2001). However, together with the environmental concerns related to high herbicide use, other concerns of an agronomic nature have also arisen in the last decades. The repeated and intensive use of herbicides with the same mechanism of action can rapidly select for shifts to tolerant, difficult-to-control weeds and the evolution of herbicide-resistant weeds, especially in the absence of the concurrent use of herbicides with different mechanisms of action or the diversification of weed control techniques (Pignata et al., 2008; Norsworthy et al., 2012; Vencill et al., 2012). This could be the case in Europe after the loss of many products (i.e., active ingredients) following the European Union (EU) pesticide review (Grundy et al., 2011). The ability of weed communities to shift in response to control practices suggests a need for more integrated and diverse approaches to weed management (Buhler et al., 2000; Mortensen et al., 2012; Santín-Montanyá et al., 2013).

Integrated weed management (IWM) is an important component of integrated pest management (IPM) that aims at preserving crop yield and grower's profit while minimizing the impact on the environment and human health through the concerted use of preventive tactics, scientific knowledge, management skills, monitoring procedures, and efficient use of weed control practices (Buhler, 2002). IWM has the potential to suppress weed densities to manageable levels, reduce the environmental impact of individual weed management practices, increase cropping system sustainability, and reduce selection pressure for weed resistance to herbicides (Harker and O'Donovan, 2013). Despite decades of research and the availability of several tools, the diffusion and level of IWM implementation is low due to gaps and barriers to IWM adoption (Buhler, 2002; Organisation for Economic Co-operation and Development, 2012; Brewer and Goodell, 2012). Consequently, one of the main challenges in European research is to develop IWM strategies that manage weed infestations with a low dependence on herbicides, preferably without side effects on the productivity and overall system economic performance (Chikowo et al., 2009; Deytieux et al., 2012). These strategies can satisfy the rising public concern about the massive use of pesticides and will significantly contribute to addressing the EU's strategic commitment to the sustainable use of pesticides by promoting the implementation of IPM, which became compulsory in the EU in the beginning of 2014 (Directive 2009/128/EC; European Parliament, 2009). However, to achieve this and promote IWM implementation, robust evidence on the sustainability of such strategies is needed to motivate their adoption by stakeholders. This can only be done through assessing and validating them at real farm scale and using existing farm equipment, under diverse climatic and soil conditions that represent the reality of European agriculture.

In order to address this challenge, a major work package within the European Project PURE (pesticide use-and-risk reduction in European farming systems with integrated pest management, http://www.pure-ipm.eu) is devoted to maize, and in particular to on-farm experimentation where IWM tools are tested in large plots in real field conditions. More specifically, this study aims at (i) testing the efficacy of IWM tools for direct weed control in maize (i.e., using methods and tools already available but not widely implemented) in on-farm experiments (i.e., real field conditions on commercial or demonstration farms, with natural weed flora), in three important and diverse European grain maize producing regions-countries against the conventional approach in each region, and (ii) performing a comparative assessment of their economic sustainability.

2. Materials and methods

2.1. Experimental sites, design, and crop management

In 2011 and 2012, nine on-farm experiments were conducted to compare the efficacy of different IWM tools for direct weed control in maize against the conventional (CON) management. Three important grain maize producing regions (southern, central, and eastern regions) were selected for these experiments that repre-

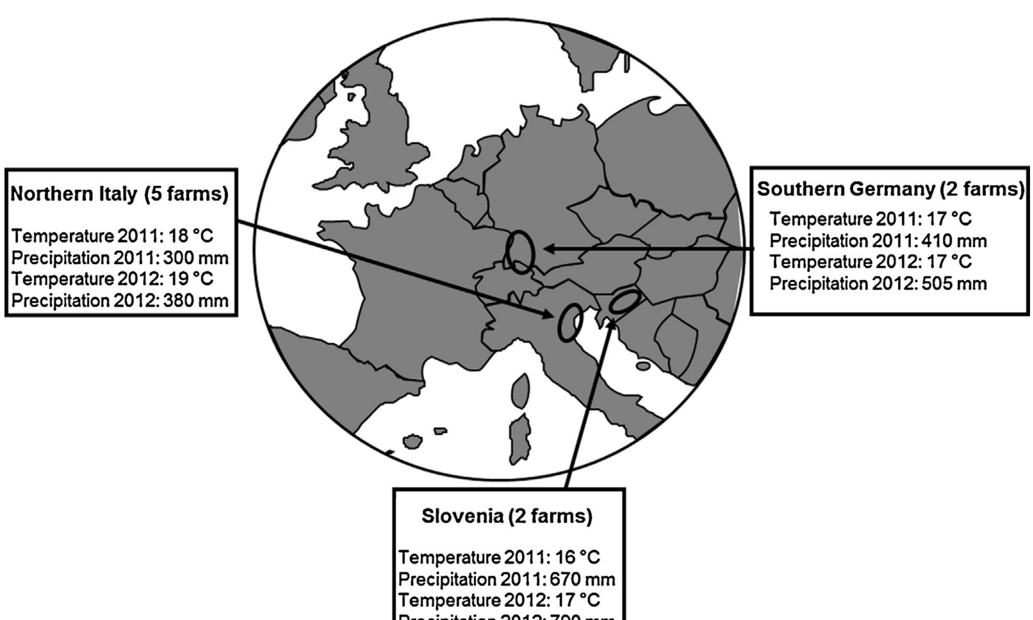

Fig. 1. Map of experimental locations per country showing the average temperature (°C) and total precipitation (mm) for each growing season (April–October) (modified after Meissle et al., 2010).