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Integrated modelling of efficient crop management strategies in response to economic damage potentials of the Western Corn Rootworm in Austria

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ABSTRACT

The spread of the Western Corn Rootworm (WCR; *Diabrotica virgifera virgifera*) challenges farmers in intensive maize production regions. We model efficient crop management strategies in response to economic damage potentials of the invasive WCR in Austria. A spatially explicit integrated modelling framework has been developed to calculate economic damage potentials from maize yield losses for a past (1975–2005) and a future (2010–2040) period with climate change. The economic damage potentials determine the choice of efficient crop management strategies considering insecticide applications, crop rotations with gradual maize limitations, fertilization intensities and irrigation. The integrated modelling framework includes the crop rotation model CropRota, the bio-physical process model EPIC, and the non-linear land use optimization model BiomAT. Typical crop rotations are simulated by CropRota at the municipality level. They are input to EPIC to simulate crop yields at the 1 km pixel resolution, which are part of the gross margin calculations entering BiomAT. Results of economic damage potentials with a 10% maize yield loss range between 3 €/ha and 180 €/ha, depending on the location, and increase to between 14 €/ha and 903 €/ha at 50% maize yield loss. The analysis of economic damage potentials shows a high regional variability. Moreover, the model results show that a decrease in maize shares combined with moderate fertilization levels is more efficient for WCR control than insecticide use. However, further crop management strategies have to be developed in order to reduce maize yield and economic losses.

1. Introduction

Maize yields are at risk due to animal pests, weeds, and pathogens (Oerke, 2006). The invasive Western Corn Rootworm (WCR; *Diabrotica virgifera virgifera*) has become a major maize pest in Europe and its prevalence is likely to increase under climate change (Diffenbaugh et al., 2008). Considerable damage has been observed and specific WCR control is indispensable in regions with intensive maize production. Integrated pest management (IPM) aims at preventive and need-based pest control activities and thus prescribes relevant management measures (Barzman et al., 2015). The efficiency of such management measures under current and future climate conditions can be analyzed in integrated modelling approaches by linking climate impacts, bio-physical processes, agronomic measures and economic evaluation of damage and abatement costs.

1.1. The Western Corn Rootworm (WCR) in Europe and Austria

The primary habitat and food source of juvenile larvae of WCR are maize roots, which limits the larvae's ability to complete their life cycle on most other crops (Spencer et al., 2009). Despite of that, the dispersal and egg deposition of highly mobile WCR adults has to be observed carefully (Levay et al., 2015; Meinke et al., 2009). In Europe, the WCR has been observed and monitored since the early 1990s (Kiss et al., 2005). Originating from Belgrade in Serbia, the pest spread in eastern Europe and was first confirmed in Austria in 2002 (Cate, 2002). The Austrian WCR monitoring shows a distribution of the pest across major crop production regions (see https://geogis.ages.at/GEOGIS_DIABROTICA.html for an interactive map). Currently, WCR pressure is predominant in regions with high maize shares, i.e. where the maize production area is large relative to the total cropland (Fig. 1). Schaafsma et al. (1999) suggested to designate regions with maize shares above 50% as ‘high-risk regions’. When the first WCR adults were detected, about 21% of maize growing areas in Austria were declared as high-risk regions, with a clear focus in south-eastern Styria (Baufeld and Enzian, 2005), a hotspot of WCR observations today.

Hotspots of maize production develop in favorable bio-physical conditions and in intensive, maize-based livestock feeding regions. In

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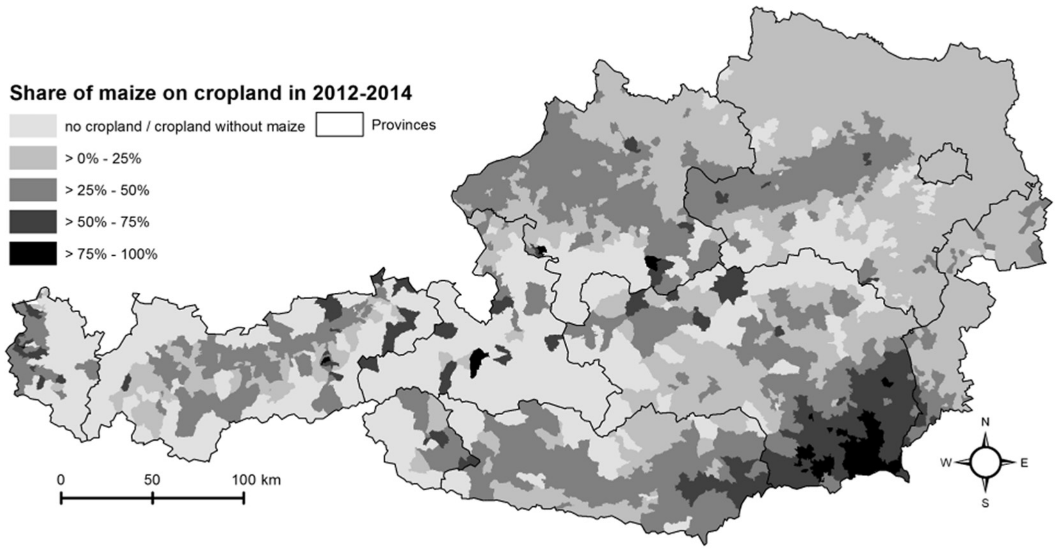

Fig. 1. Average share of maize on cropland at the municipality level in 2012–2014.
Source: IACS (BMLFUW, 2015a).

Austria, industrial demand for grain maize was almost as high as the amount used for livestock feeding in the last decade (Sinabell et al., 2014). Profitability of maize production is attributed to high yield potential and little labor demand compared to the production of other crops (AWI, 2016). Economic damage from WCR establishment is thus related to yield loss as well as additional variable costs and labor demand for pest control (Kehlenbeck and Krügener, 2014).

1.2. WCR control

IPM is defined as a sustainable and profitable crop protection method (Boller et al., 2004). It has been promoted for European crop production in the Directive 2009/128/EC (European Parliament and the Council of the European Union, 2009), which has been implemented in Austria at regional level (see e.g. Burgenländisches Pflanzenschutzmittelgesetz, 2012; NÖ Pflanzenschutzmittelgesetz, 2012; Steiermärkisches Pflanzenschutzmittelgesetz, 2012). A survey among agricultural extension experts in several European countries outlines a range of potential WCR control measures within IPM (Meissle et al., 2010). Irrigation and fertilization may strengthen root regeneration after larval feeding and support the stabilization of maize plants after lodging. A robust root system may also be developed by early or very late planting dates (Meissle et al., 2010). Additionally, the choice of maize hybrids matters as they show a variability in injury tolerance and recovering potential (Urías-López and Meinke, 2001). Biological control options, a key measure in IPM, have been studied in field experiments by Pilz et al. (2009). Entonompathogenic nematodes have shown a comparable efficacy to soil insecticides, whereas entomopathogenic fungi resulted in a lower efficacy (Pilz et al., 2009). Investigations on the phenology of the pest provide knowledge on the crop-pest-interactions (Spencer et al., 2009) and reveal the spectrum of WCR management measures (Furlan and Kreutzwieser, 2014). Variability in the efficacy of measures is observed between study locations and years and indicates a large impact of the environment and population dynamics on actual maize yield losses (Dun et al., 2010; Toepfer and Kuhlmann, 2005). Besides WCR-specific agents, crop rotations are seen as an important crop management measure to interrupt the life cycle of WCR (Kehlenbeck and Krügener, 2014; Schuster, 2016; Szalai et al., 2014). This is because continuous cultivation and high regional densities of maize are required for the establishment of WCR populations. Specialist pests like the WCR are more affected by land use changes than generalists (O'Rourke and Jones, 2011). This makes crop rotations highly efficient, as continuous production of a single crop can increase its susceptibility to diseases or insect pests (Schaafsma et al., 1999; Tilman et al., 2002). Bertossa et al. (2013) report on a successful reduction of WCR by crop rotations in Swiss field trials, but they suggest that immigration from other fields may contribute to the final number of adults on a rotated field. Moreover, combining pest control methods is inevitable as a high selection pressure of effective methods can promote the development of resistant pests (Pimentel, 2005).

The spectrum of WCR control measures indicates that effective control requires profound knowledge on agro-ecosystems, including knowledge on pest phenology and behavior as well as on climatic conditions (Furlan and Kreutzwieser, 2014; Meissle et al., 2010). Moreover, climate change will likely amplify crop pests and diseases. Impacts from climate change scenarios on soil temperature and induced effects on the phenology of WCR have been simulated for Austrian fields until 2050 and show a shift to earlier pest occurrence (Eitzinger, 2012). Results indicate that the first larvae occur 10–19 days and the first beetle 16–24 days earlier compared to current conditions at an average temperature increase of about 2 °C. Consequently, monitoring of soil temperature is suggested as a tool to improve WCR prediction and control.

1.3. Economic damage of WCR infestation

Economic implications of WCR for maize production regions have been assessed by Baufeld and Enzian (2005). They analyzed maize production data for selected EU member states and Switzerland based on the above-mentioned classification by Schaafsma et al. (1999), who define regions with maize shares exceeding 50% of cropland as high-risk regions. High-risk regions have a significant share of cropland in continuous maize, which can foster a rapid growth of WCR populations. In these regions, WCR population densities approach economic thresholds faster due to a higher colonization rate, compared to low-risk regions (Baufeld and Enzian, 2005).

Pest spread and the anticipated arrival of WCR in climatically suitable production regions in Europe have been simulated by Wesseler and Fall (2010) in order to quantify potential economic damage in a no-control situation for several EU member states, which is proposed as an upper limit of costs for pest control programs. The authors suggest that spread control by national authorities can delay WCR infestation. WCR control strategies are analyzed in more detail by Kehlenbeck and Krügener (2014). They calculate cost-benefit-ratios for WCR