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Spatial analysis of maize cropping systems to relieve crop pest pressure in Austria

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Abstract

Maize production in Austria is at risk because few appropriate pest control measures are currently available. Production opportunities change if pests reach economically relevant levels. In the case of the Western Corn Rootworm (*Dicabrotica virgifera virgifera*), intensive maize production contributes to population establishment and vice versa leads to maize yield losses. We assess the opportunity costs of crop rotations at different levels of pest pressure. Additionally, maize is substituted by other crops in crop rotations due to policy regulations. Results show that the substitution of maize by other crops reduces gross margins of crop rotations, but vulnerability to pest pressure in terms of yield losses exceeds the impacts of alternative crops on gross margins. Monitoring results and analyses of crop production in Austria point out the close relationship between pest populations and maize cropping in the last decade. Thus, there is a demand for spatially explicit modeling of pest control measures. In the outlook of this paper, potential approaches for integrated and coordinated pest management implementation at the landscape scale are described.

Keywords Western Corn Rootworm, crop rotations, spatial modeling

1 Introduction

Austrian crop production is currently challenged by the establishment of an invasive species. The propagation of the highly mobile Western Corn Rootworm (WCR; *Diabrotica virgifera virgifera*) causes considerable regional damage on maize production with losses up to 100% in some cases. Since the early nineties, when the first adult beetles were registered in Serbia, the population of WCR increased and reached Austria in 2002 (Kiss et al., 2005a). In the following decade, the invasive pest became a severe threat to maize growers in a couple of regions. The former quarantine pest status was abandoned in 2014 (by repealing decision 2003/766/EC), as a consequence of a failed prevention and WCR establishment in several EU Member States¹.

The primary habitat of juvenile larvae of WCR is maize (Spencer et al., 2009), which is also one of the main feed crops for pig and cattle fattening as well as dairy in Austria. Pork production is closely related to maize production and regionally concentrated (BMLFUW, 2015), which fosters pest persistence. Former high shares of maize in some regions are further increased due to a growing demand from industry, where maize is processed into glucose, ethanol, or starch (WIFO, 2014). Intensive maize production is incentivized by multiple demand, shows a high yield potential compared to other crops in Austria, and is comparably easy to manage.

Crop production is dependent on pest control activities, as biotic factors (which include weeds, animal pests and pathogens) contribute to crop losses. As opposed to abiotic factors (irradiation, water, temperature and nutrient availability), damage from biotic factors can be managed by the use of chemical, mechanical, biotechnological and biological measures. In maize, the actual yield is mainly determined by weeds, which usually account for a higher loss than the sum of animal pests, pathogens, and viruses (Oerke, 2006). However, such ranking can be reversed as a consequence of crop management (e.g. maize monoculture, soil erosion) or ecological disturbance,

¹COMMISSION IMPLEMENTING DECISION of 6 February 2014 repealing Decision 2003/766/EC on emergency measures to prevent the spread within the Community of *Diabrotica virgifera* Le Conte (notified under document C(2014) 467) (2014/62/EU)

e.g. the introduction of an invasive pest. In Europe, maize as only one of several crops in a particular crop rotation is the primary integrated pest management control option for WCR, for both the containment of the pest or its eradication (Kiss et al., 2005b). Furthermore, crop rotations also contribute to positive agronomic impacts beyond pest suppression (Vasileiadis et al., 2011). Due to economic benefits of maize production, however, agronomic advice on limited occurrence of maize in a particular crop rotation has only partially been implemented by farmers so far and has been frequently replaced by alternative chemical pest management options. Such demand for chemical control measures is confronted today with a limited range of approved pre- and post-emergence pesticides. It poses an additional risk on farmers, who rely to a large degree on the availability of pesticides.

While farmers can manage certain pests at field or farm level, effective WCR control seems to demand coherent strategies beyond the farm level today. This is particularly true for landscapes dominated by small fields and a high share of maize in the crop rotations. Given such circumstances, WCR may easily survive in the neighboring maize crop field despite the cultivation of non-maize crops on a particular field.

WCR monitoring results support this hypothesis. They indicate a close relationship between land use and pest occurrence. Therefore, we suggest that pest control strategies may be effectively implemented in the framework of common pool management. Consequently, coordinated action may facilitate integrated pest management and may contribute to a reduction of farm vulnerability. First steps towards landscape level management are processing and analyzing i) empirical data on the occurrence of maize in crop rotations, ii) the significance of crop rotations on pest control and iii) the economic implications of alternative crop rotations. In this paper, we present first results on points i) to iii) above. Furthermore, we give an outlook on subsequent research.

2 Methodology

In the first step of our analysis we describe and prepare empirical data for subsequent modeling tasks. Annual shares of crops at the municipality level are available from IACS (Integrated Administration and Control System, 2000-2014) and are dissected to identify the regional relevance of maize. The share of maize (grain maize and silage maize) on cropland in Austria is presented to depict the relevance of strategies for WCR control at regional scales. Subsequently, we select a case study region, which is characterized by a high specialization in maize production.

The level of pest pressure due to WCR infestation is indicated by monitoring results. The implementation of WCR monitoring was mandatory at the time of the quarantine status of WCR and was continued after the abolition of the status. Catch rates from 2004 onwards are made available from eight out of nine provinces in Austria and are detected by positioning pheromone or yellow traps in potential locations of WCR occurrence. The traps have been arranged according to the expected area of distribution and in previous hot spots. A weekly inspection of the traps has been carried out over the entire growing season. Catch rates feed into a GIS model to reveal dispersion patterns over time and allow for a descriptive analysis of maize shares in a rotation and pest occurrence. Several years of pest monitoring point to the efficiency or inefficiency of rotating maize with various other crops compared to monocultures. To analyze the economic impact of the alteration of maize-intensive cropping systems, we calculate gross margins for alternative crop rotations based on standard gross margin calculations from the Federal Institute of Agricultural Economics (AWI, 2015). In the outlook of this paper, we present how these results may feed into an extended modeling framework to implement integrated pest management and optimize pest control measures at landscape scales.

3 Results and discussion

Cropland in Austria is concentrated in the eastern regions, which are characterized by optimal agronomic cropping conditions. The observed crop shares at the municipality level confirm the close relationship of livestock production and maize cultivation, which is concentrated in the south-east of Austria and in parts of Upper and Lower Austria. Figure 1 displays the average maize shares in Austrian municipalities in the last fourteen years. Frequent regional maize shares from 40% upwards point out the relative importance of maize compared to other crops.

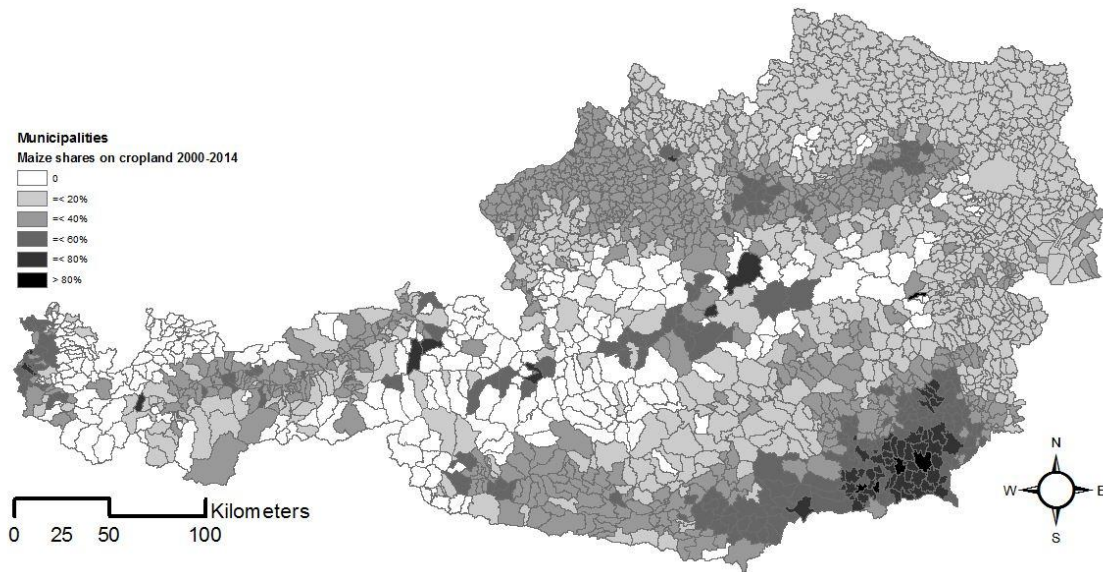
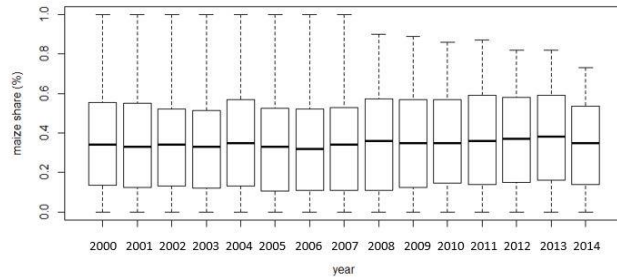
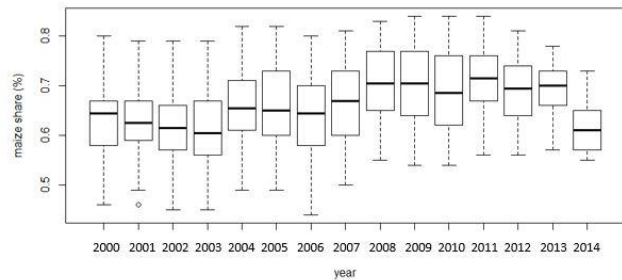


Figure 1: Average maize shares at the municipality level in 2000 to 2014; Source: own map based on data from IACS (2015)

The analysis of maize shares reveal the regions which provide extensive habitats for maize pests like WCR. In Europe, the origin of the spread of WCR was in the Balkan region. Moving northwards, the south-eastern border of Austria was at particular risk. Figure 2a shows annual maize shares at municipality level in Styria from 2000 to 2014, a province located in the south-east of Austria (see also figure 3). Baufeld and Enzian (2005) identified high-risk areas in several European countries by applying a similar approach. Regions with maize shares above 50% of arable land are concerned with high risk of damage due to WCR and can be found e.g. in northern Italy, Bavaria, and the Rhine Valley. We confirm their result that the south-east of Austria is a high-risk area. The district South-East Styria (in German: Südoststeiermark), is characterized by the highest shares in Austria (Figure 1, dark coloring), which have been typical for this region over the last 15 years (Figure 2b). However, latest data from 2014 indicate a decline in maize shares. It may be due to adaptation to pest pressure from WCR, or other influences such as declining average producer prices since 2012 (Statistik Austria, 2015).



(a)



(b)

Figure 2: Annual maize shares at the municipality level in Styria (a) and in South-eastern Styria (b); Source: IACS (2015)

In Styria, catch rates of WCR indicate that the high densities of maize in several regions attracted the pest and enabled high growth rates in the course of a few years. The average number of beetles caught per trap increased from 0.8 beetles in 2004 (160 traps) to 3008 beetles in 2014 (24 traps) whereas the distribution of catch rates varies strongly between the traps. Nevertheless, the sum of caught beetles refers to huge populations at the local level. Correlation of pest and host crops is insufficient as there is a limited number of traps, which are randomly distributed. Moreover, we assume that due to inhomogeneous landscapes and production activities catch rates vary strongly over spatial gradients and cannot be interpolated at regional scales. Figure 3 shows actual catch rates in 2014. Additionally we show the potential infestation area derived from the flying abilities of the pest, i.e. 10km to 40km per year. The high mobility of WCR adult beetles is responsible for the fast spread of the pest. Therefore, effective control measures inevitably call for deliberate spatially coordinated strategies.

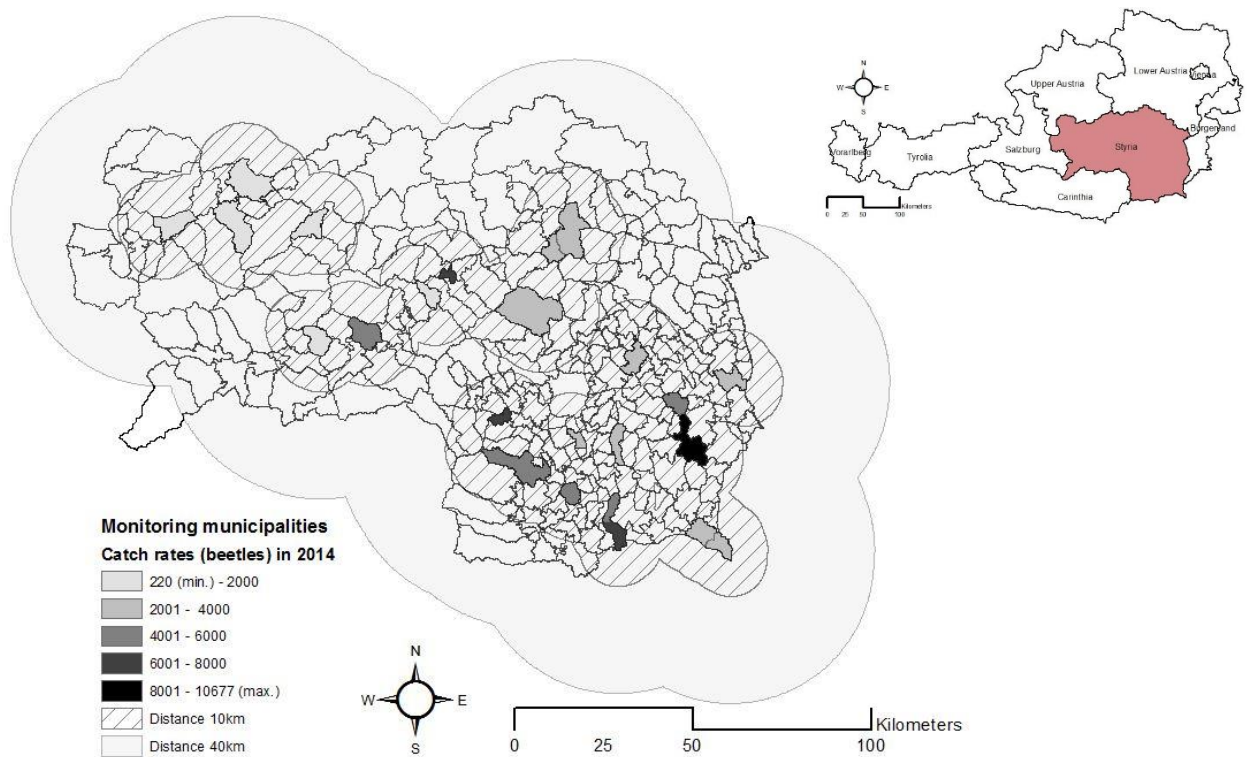


Figure 3: Monitoring results for Styria in 2014 and potential annual flight radii of the Western Corn Rootworm;
 Source: Own map based on data from Amt der Steiermärkischen Landesregierung (2015)

Consequently, crop rotations with high shares of maize conduce to the development of WCR populations, because the life cycle of the pest can be completed repeatedly. Immigration of WCR females from neighbouring fields have to be considered for the same reason. In general, Austrian farmers do not apply insecticides in maize. Coated seeds with certain active ingredients had been partially applied, but are affected by the ban on neonicotinoids in 2013². Today, there are only a few approved active ingredients available to farmers, some of which afford special application technologies.

Economically, the substitution of maize by another crop raises concerns by farmers particularly in case of on-farm feed use, a common practice for pig fattening especially in South-east Styria. Experts frequently raise the perception that alternative crops to maize have often lower crop yield potential and digestibility, are incompatible to on-farm feeding technology, or are more complicated and risky to grow. With respect to the latter, insufficient knowledge can be an important obstacle for farmers in the first years of implementing a new crop in a region. In regions with pest hot spots, concomitant application of insecticides and biological methods in maize is therefore highly recommended. We calculated the impact of maize substitution in terms of

² COMMISSION IMPLEMENTING REGULATION (EU) No 485/2013 of 24 May 2013 amending Implementing Regulation (EU) No 540/2011, as regards the conditions of approval of the active substances clothianidin, thiamethoxam and imidacloprid, and prohibiting the use and sale of seeds treated with plant protection products containing those active substances

opportunity costs in crop rotation gross margins. Scenarios on crop rotations are developed adapting to regional regulations such as comprising maize breaks in every second, third or fourth year. In a second step, we consider maize yield losses due to WCR as an impact analysis of the “no-control” scenario. Figure 4 shows gross margins for the crop rotation scenarios with different shares of maize and four levels of pest pressure. To date, no empirical data on WCR-related crop losses in Austria are available. In a survey carried out by KeyQUEST market research (2015), affected farmers estimate their own yield losses in 2014 between lower than 10% and 30%. Single farmers have been affected by total yield loss. Kehlenbeck and Krügener (2014) report on yield losses in south-eastern Europa, ranging from 10% up to 30% depending on climate and maize density. Pest pressure in our scenarios is set according to this results, namely 5%, 20% and 30% yield losses at low, intermediate and high pest pressure, respectively. The shares of maize are confirmed to policy regulations, e.g. 67% of maize represents the constraint of a maize break every three years.

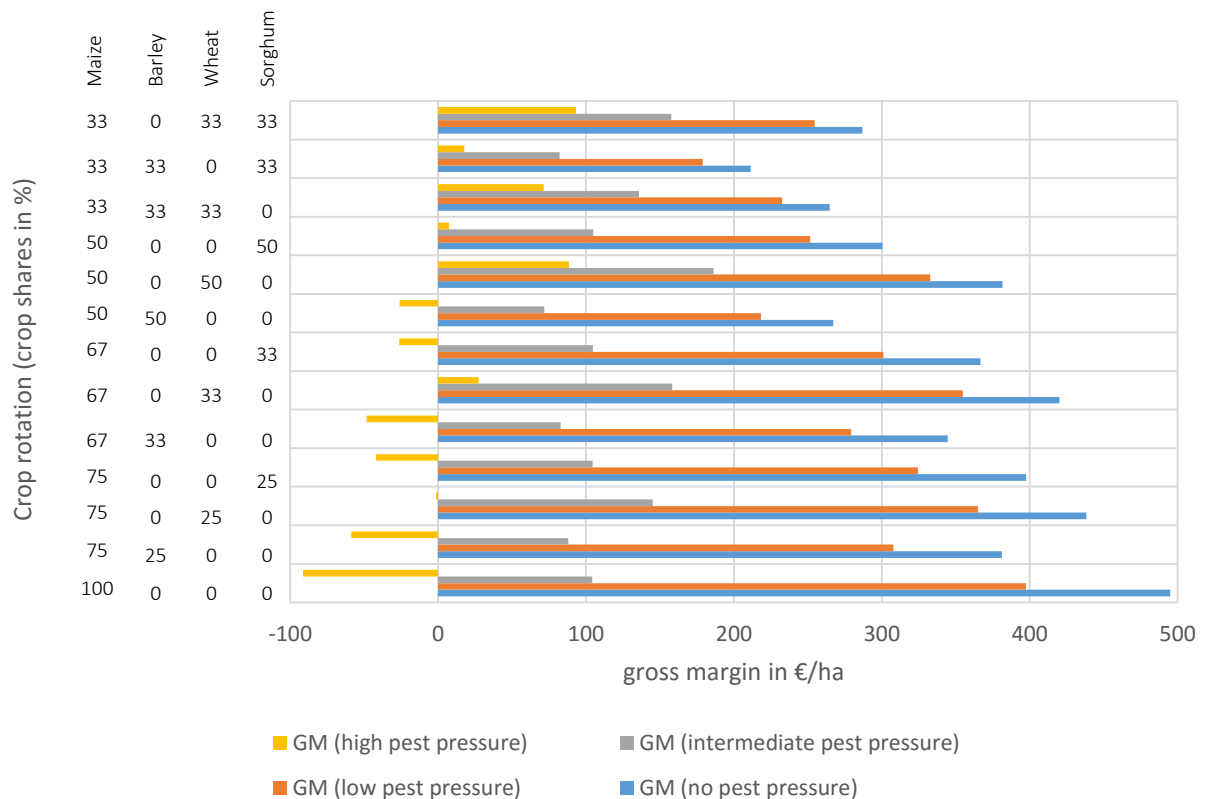


Figure 4: Crop rotation gross margins (GM) for five levels of maize shares and four levels of pest pressure; Source: AWI (2015), LfL (2015), Provincial regulations

The results in figure 4 indicate that maize accounts for high gross margins compared to other crops. For example, a crop rotation with 100% maize (monoculture) yields up to 500 €/ha assuming no pest pressure. Gross margins of alternative crops like winter barley, winter wheat or sorghum yield are at lower levels, i.e. 40 €/ha, 270 €/ha and 105 €/ha, respectively, for the situation in the years 2008-2013. Obviously, there is a high comparative advantage in maize production. As a consequence, reductions in gross margins increase with yield losses due to pests like WCR. The

substitution of maize by other crops (e.g. winter wheat, barley or sorghum) reduces gross margins in a situation with no pest pressure on maize, but results in higher gross margins at higher levels of pest pressure. Therefore, cropping systems with reduced shares of maize are less vulnerable to WCR infestations. At the farm level, the costs of the avoided losses can be measured by the sum of crop rotation costs and feed purchase. The economic threshold is driven by the risk of crop losses, on-farm restrictions and opportunities. If we would consider pesticide use, their benefit could be quantified as the efficiency in terms of prevented losses minus application costs. Kehlenbeck and Krügener (2015) include expected efficiency rates in their calculations, but it is admitted that these rates are closely related to optimal conditions in climate, timing and technology. Due to a lack of empirical information on the efficiency of pest control measures in WCR defense, this is not included in our study.

As far as the economic threshold is concerned, the level of pest pressure differently affects production systems. Adaptation costs for example differ between cash crop farms and dairy farms. In a case study for Bavaria (south-east Germany), pig fattening and cash crop production show low economic thresholds. In dairy farming, the economic threshold is reached at higher levels of crop losses due to higher adaptation costs (Köhler and Schätzl, 2014). This is of special interest, as production conditions in Bavaria are similar to Austria.

4 Conclusions and Outlook

In this section, we present conclusions on our results and provide a preview on subsequent research activities.

The presented results confirm a close relationship between long-term maize production and pest development. The mobility and the potential of population growth of the Western Corn Rootworm have not been considered adequately in the past. High levels of crop losses due to WCR have been observed and indicate the high vulnerability of maize-intensive regions. As a consequence, farmers need to adapt to the presence of the pest by the implementation of different pest control measures. Adaptation to WCR is likely to cause longer-term decisions at the farm level. Results on crop rotation gross margins reveal that there is a high economic incentive to continuous maize cropping in case of low pest pressure. Alternative crops and alteration in livestock feeding may induce further adaptation on the farm besides single crop substitution in crop rotations. Policy regulations as implemented in this analysis emphasize the demand for economically beneficial strategies.

With respect to future research efforts, the preliminary results presented in this paper raise the important question which effective pest control measures are within the scope of farmers' capabilities. Consequently, it will be important to include the perspectives and needs of farmers in the interpretation of our analyses. When farmers take into account spatial aspects of pest control, they might conceive a set of barriers. Special attention has to be paid to continuous short-distance diffusion of high economic concerns, which highlights the importance of cooperation. In this context, the information transfer and training demand outlined by Furlan and Kreutzwieser (2015) is of crucial importance. It includes on-time information on pest occurrence during the cropping season, closing knowledge gaps on pest development and management as well as offering a platform for meeting and coordination of farmers.

Besides increasing awareness and information, we propose several additional tools that might contribute to address the challenge of WCR management. For the analysis of alternative crop production strategies, data from IACS are valuable to consider the Austrian circumstances. At the national level, crop rotations can be derived from observed cropping areas at the municipality level. For example the model CropRota (Schönhart et al., 2011) can be applied to generate typical crop

rotations from observed crop data as well as crop rotation alternatives with reduced shares of maize and inclusion of crop substitutes. To detect the overall impact of alternative maize production strategies, CropRota can be linked to an economic optimization model. The spatial bottom-up land use optimization model BiomAT is designed for computing opportunity costs of alternative strategies in cropland pixels (Stürmer et al., 2013). The bio-physical process model EPIC (Williams, 1995) provides simulated crop yields under various crop and pest management strategies, which can be supplemented by production costs from standard gross margins for Austria (AWI, 2015). Scenarios can be used to take into account different levels of pest pressure and pesticide availability. The scenarios are able to provide insights into consequences for maize production in Austria under unfavorable circumstances, which affect food and feed production as well as up- and downstream industries.

The analysis points out that pest management in Austria can be improved by focusing on temporal and spatial characteristics of WCR. The temporal dimension is part of the procedure of integrated pest management (IPM; directive 2009/128/EC) and is demonstrated for WCR by Furlan and Kreuzwieser (2015) in a practically relevant way. To implement IPM techniques into a modeling framework, different decision making tools have to be evaluated to select appropriate ones for modeling and for practical implementation. This approach is highly valuable for pest management, because pest control is adjusted to an actual demand. Monitoring data of adult beetles are one of several indicators that indicate pest levels. Others are soil temperatures (Eitzinger, 2012) or temperature sums (Lütke Entrup et al., 2013).

As demonstrated in figure 3, the spatial dimension of pest management is the main challenge in WCR control. The single farm perspective needs to be extended to consider the temporal and spatial dimension of effective pest control. Therefore, an essential aim should be an extension of the modeling issues to the landscape scale. Carrasco et al. (2012) and Szalai et al. (2014) already published models that contribute to this research questions. Although data on landscape composition are hardly available, a functional arrangement of fields can be simulated in a pixel frame. The design of measures that reduce pest pressure at the landscape scale therefore include cooperative activities of neighboring pixel as well as a variety of pest control activities at the pixel level. Spatio-temporal coordination of chemical and biological pest control measures enhances their efficiency. Pixel can also contain information on average farm endowments to take into account varying types of farms. In practice, another dimension may be crucial for effective pest control at the regional scale. We already mentioned the necessity of knowledge transfer to farmers as one social aspect. Additionally, the willingness of farmers to communicate and cooperate is essential for a successful implementation of the discussed pest control measures. Innovative EU programs such as the European Innovation Partnerships (EIP) and its Operational Groups (OG) are one trigger towards productivity gains in agriculture (www.eip-agri.eu).

Summarizing, a landscape approach can analyze comprehensive pest management in terms of productivity and structural change. The integration of different models enables to figure out costs and benefits of area-wide solutions compared to single farm efforts on pest control and will contribute to the understanding of IPM.

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