Integrated modelling of measures to control the Western Corn Rootworm in Austria

Integrierte Modellierung von Maßnahmen zur Kontrolle des Westlichen Maiswurzelbohrers in Österreich

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Summary

The Western Corn Rootworm (WCR) has become a major pest to maize in Austria in recent years. We model damage potentials of maize yield losses and crop management options for WCR control in Austria. The crop management options include maize restrictions in crop rotations as well as insecticide applications. Our integrated modelling framework sequentially links a crop rotation model, a bio-physical process model and a bottom-up land use optimization model and represents Austrian cropland at 1 km resolution. We identify several hot spots for high WCR damage potentials, which are related to regional maize yield levels and maize shares in crop rotations. The results show that the reduction of maize in crop rotations is more beneficial than insecticide applications in many agricultural production areas.

Keywords: Western Corn Rootworm, maize production, pest management, integrated modelling, Austria

Zusammenfassung

In den letzten Jahren hat sich der Westliche Maiswurzelbohrer (MWB) zu einem bedeutenden Maisschädling in Österreich entwickelt. Wir untersuchen das Ertragsverlustpotenzial im Maisanbau sowie verschiedene MWB Kontrollmöglichkeiten. Letztere inkludieren die Reduktion des Maisanteils in der Fruchtfolge und die Insektizidanwendung. In einem integrierten Modellverbund kombinieren wir ein

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Fruchtfolgemodell, ein bio-physikalisches Prozessmodell sowie ein ökonomisches bottom-up Landnutzungsoptimierungsmodell. Darin wird das Ackerland in Österreich mit einer Auflösung von 1 km abgebildet. Die Ergebnisse zeigen mehrere Hotspots eines hohen Ertragsverlustpotenzials, welches von regionalen Maiserträgen und Maisanteilen in der Fruchtfolge mitbestimmt wird. Die Ergebnisse zeigen auch, dass bei einem hohen Ertragsverlustpotenzial die Reduktion des Maisanteils in der Fruchtfolge an vielen Standorten vorteilhafter ist als der Einsatz von Insektiziden.
Schlagworte: Westlicher Maiswurzelbohrer, Maisproduktion, Schädlingsbekämpfung, Integrierte Modellierung, Österreich

1. Introduction

Crop losses due to pest infestation reduce the productivity of farming systems. Therefore, pest control is an integral component of crop production to prevent quantitative, qualitative and subsequent economic losses (OERKE, 2006). In Austria, the highly mobile invasive Western Corn Rootworm (WCR; *Diabrotica virgifera virgifera*) can cause maize yield losses due to larval feeding on maize roots with reduced plant stability and growth. Additionally, adult beetles of WCR feed on maize silks reducing grain yield potentials.
Maize is a major crop due to favourable cropping conditions in some agricultural production regions in Austria. Furthermore, it is highly demanded by livestock farmers and the processing industry. In the last 25 years, the share of maize on total Austrian cropland has fluctuated around 20%, with a slight increase from 2000 onwards (SINABELL et al., 2014). Hotspots of maize production are observed in the South-East of Austria. Table 1 presents total maize areas and average maize shares by quartiles of maize shares on cropland in municipalities, i.e. ≤25% (quartile 1), >25-50% (quartile 2), >50-75% (quartile 3), >75% (quartile 4). WCR has been monitored via traps since its first detection in Austria in the early 1990ies and in accordance with obligations on the (former) quarantine status of WCR[1]. Current catch rates confirm that WCR has

[1] Commission implementing decision of 6 February 2014 repealing Decision 2003/766/EC

Tab. 1: Average maize shares on total maize areas in municipalities by quartiles of maize shares on cropland in Austrian municipalities in 2012-2014. Note: 1,632 municipalities with 277,805 hectares of maize in total.

Quartiles of maize shares	Share of Municipalities (in %)	Share on total maize area (in %)	Share of maize on cropland in municipalities (in %)
Quartile 1	67	36	11
Quartile 2	26	42	34
Quartile 3	6	16	62
Quartile 4	1	6	79

Source: OWN CALCULATIONS

already spread all over Austria. The sum of regional WCR control measures determines the regional pest pressure. However, the level of maize yield loss on a field depends on the farmers' management. With respect to pesticides, only a limited number of WCR control measures is available since effective pesticides[2] have been banned due to concerns about harming effects on bees. Crop rotations with low shares of maize are a particularly effective measure against WCR. Consequently, some Austrian provinces established regulations on the cultivation frequencies of maize on a particular field in order to suppress population development.

We have developed an integrated modelling framework to assess potential economic damages from WCR infestation on Austrian cropland and optimal crop management portfolios for WCR control, including insecticide applications and alternative crop rotations as control measures (see section 2). Section 3 of this article presents the results, which are summarized and discussed in section 4.

2. Material and methods

2.1 Integrated modelling framework (IMF)

The crop rotation model CropRota (SCHÖNHART et al., 2011) is used to compute typical crop rotations at municipality level from observed

[2] Commission implementing regulation (EU) No 485/2013

land use in 2012-2014 (EU Integrated Administration and Control System (IACS) data pool provided by BMLFUW, 2015) and expert knowledge. Cereals and grain sorghum are considered as substitutes for maize in alternative crop rotations in order to comply with WCR control policies with varying maximum maize shares. Extending the cultivation of grain sorghum is proposed by agricultural experts, because it enables substitution of maize in livestock diets and requires similar crop management. In total, 23 crops are currently considered in CropRota. The typical crop rotations at municipality level are proportionally assigned to the 1 km cropland pixels within the municipalities for modelling purposes. The reference crop rotation system (REF) represents average land use in 2012-2014. Five alternative WCR-specific crop rotation systems are derived from REF by employing upper limits for maize at 75% (75M), 66% (66M), 50% (50M), 25% (25M), and 0% (00M) and considering cereals and grain sorghum as substitutes in the crop rotations.

Data on topography, soil types, crop management and climate serve as input to the bio-physical process model EPIC (Environmental Policy Integrated Climate; WILLIAMS, 1995). These data are available for 36,498 cropland pixels at a resolution of 1 km. The cropland area per pixel is derived from IACS data of 2010 as described in GUGGENBERGER et al. (2012). Historical climate data (1975-2005) at a temporal and spatial resolution of 1 day and 1 km are provided by STRAUSS et al. (2013) and include temperature, solar radiation, precipitation, wind speed and relative humidity. EPIC provides simulation outputs on dry matter crop yields by crop management regimes at each 1 km cropland pixel over 31 years. Beside crop rotations, three fertilization intensities (low, moderate and high) and optional irrigation for the high intensity level complement the crop management regimes.

Dry matter crop yields, fertilizer inputs (nitrogen, phosphorus) and irrigation water amounts of the six crop rotation systems and four management regimes are input to the economic optimization model BiomAT. BiomAT maximizes net returns from crop production at the national level (STÜRMER et al., 2013; MITTER et al., 2015). The model is calibrated to the REF crop rotation system by using a PMP (Positive Mathematical Programming) approach. Crop gross margins are calculated for all six crop rotation systems and four management regimes. The variable production costs from the Standard Gross Margin Catalogue of the Federal Institute of Agricultural Economics (AWI, 2016) include costs for machinery use, seeds, insurance, and fertilizers. Crop protection costs are available for wet and dry cropping conditions. Consequently, we categorize each pixel accordingly using the 31-years average annual precipitation amount and identify whether it is below or above 650 mm (STRAUSS et al., 2013). The costs for insecticides for WCR control as well as their application rates are provided by the Chamber of Agriculture in Styria (LK STEIERMARK, 2016). Insecticide applications are considered in the two maize-intensive crop rotation systems 75M and 66M. Two insecticide applications are combined with the fertilization intensities high and irrigation, whereas one application is combined with the moderate fertilization intensity. No insecticides are considered at the low fertilization level. Average producer prices from 2010-2014 are taken from statistics of AWI (2016) to calculate revenues for crop production. Standard management data are not available for grain sorghum. We therefore calculate variable production costs based on information provided by VERSUCHSREFERAT STEIERMARK (2016). A regional single farm payment for cropland (283 €/ha) and agri-environmental premiums for moderate (50 €/ha) and low fertilization intensity (115 €/ha) are considered in the gross margin calculations.

The initial linear objective function of BiomAT is used to compute marginal values for the six crop rotation systems i.e. REF, 75M, 66M, 50M, 25M, and 00M. In the PMP procedure, these marginal values are used in the non-linear objective function, which enables a calibration of the REF crop rotation system (SCHMID and SINABELL, 2005).

2.2 IMF application for WCR impact analysis

In the first step of our analysis, we compute WCR damage potentials from maize yield losses by calculating the difference in gross margins with and without maize yield losses (in €/ha). The maize yields in the REF crop rotation system are reduced by 20% and 70% in the damage potential analysis, which cover an intermediate and an extreme situation of WCR infestation. Secondly, we model the opportunity costs of maize area abandonment in the cropland pixels considering crop rotations REF and 00M. Thirdly, we assess optimal crop management portfolios in responding to WCR damage potentials from maize yield losses. Crop management options for WCR control include alternative crop rotation systems and insecticide applications. We also account for different rates of insecticide efficiency (i.e. 100% and 90%) to acknowledge various challenges farmers face. For example, narrow application time frames and active ingredients are two of the key factors for successful control of WCR adults.

3. Results

3.1 Potential damage from WCR

Potential damage due to WCR infestation is computed as the difference in gross margins with and without maize yield losses. Reduced revenues are the consequence of maize yield losses, while production costs are assumed to be unaffected. Table 2 presents median and mean as well as first and third quartiles of potential WCR damage at maize yield losses by quartiles of maize shares on cropland in municipalities. For instance, with 20% (70%) maize yield loss, potential damage is between 6 (20) €/ha and 335 (1,170) €/ha in quartile 1 and between 52 (182) €/ha and 351 (1,230) €/ha in quartile 4 of maize shares. A median damage of 216 €/ha at 20% maize yield loss is exceeded on up to 15,680 ha in the most intensive maize production areas (quartile 4). At 70% yield loss, severe damage levels higher than 1,000 €/ha are possible on 11,700 ha of the respective maize area in quartile 4. The hotspots of potential high yield loss and severe economic damage are located in the South-East of Styria and on small cropland areas in other provinces.

Tab. 2: WCR damage potentials in €/ha with 20% and 70% maize yield losses by quartiles of maize shares on cropland in municipalities. Note: Q1 denotes first and Q3 third quartile in damage potentials.

Quartiles of maize shares	Maize yield loss level							
	20%				70%			
	Q1	Median	Mean	Q3	Q1	Median	Mean	Q3
Quartile 1	36	55	59	89	125	193	240	311
Quartile 2	55	80	91	112	192	281	318	395
Quartile 3	88	120	150	214	309	421	525	752
Quartile 4	120	216	215	306	419	755	751	1,070

Source: Own calculations

3.2 Opportunity costs and maize abandonment

In the REF crop rotation system, maize is grown on 277,805 ha in Austria, covering about 21% of total cropland. We present the relative abandonment of maize areas with increasing levels of opportunity costs (Figure 1). A reduction of maize shares in crop rotations on individual fields is a core measure in WCR population control. The boxplots show that median and variability in relative maize area abandonment increase with the level of opportunity costs. It implies that a considerable reduction of maize production entails high opportunity costs for farmers.

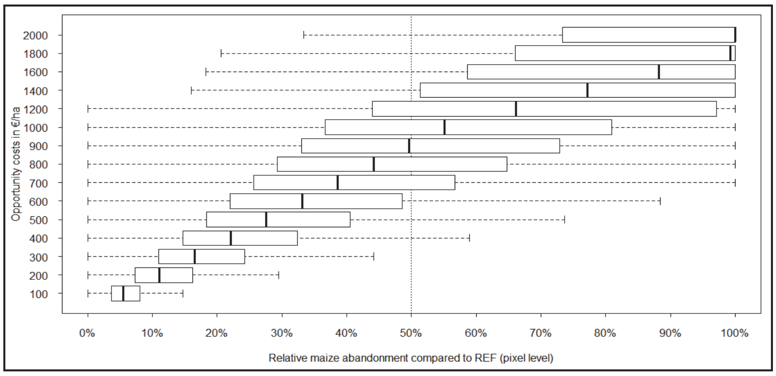

Figure 1: Boxplots of relative maize abandonment at opportunity costs between 100 €/ha and 2,000 €/ha. Note: Outliers are not shown.
Source: OWN CALCULATIONS

3.3 Optimal WCR management portfolios

Sections 3.1 and 3.2 provide model results on the damage potential of WCR and opportunity costs of maize abandonment. Here, we present optimal crop management portfolios in responding to damage potentials from maize yield losses (i.e. 20% and 70%). Two levels of insecticide efficiency are considered in the analysis, i.e. 90% and 100%. Table 3 presents the shift in crop rotation systems on Austrian cropland resulting from portfolio optimization. Results show that crop rotation systems with reduced maize shares (i.e. 50M, 25M and 00M) are preferred over maize-intensive rotations with combined insecticide applications (i.e. 75M and 66M) at both maize yield loss levels. The total maize area declines by 13% at a maize yield loss of 20% and insecticide efficiency of 100%, compared to the reference situation. At 70% maize yield loss and 100% insecticide efficiency, the total maize production area declines by 36%, whereas the share of maize-free crop rotations rises.

Tab. 3: Optimal crop management portfolios for WCR control by maize yield losses of 0%, 20% and 70% as well as insecticide efficiencies of 90% and 100%.

Maize yield loss level	Insecticide efficiency	Maize area in ha	Crop rotation system in % of cropland					
			REF	75M	66M	50M	25M	00M
0%*	NA	277.800	100,0	0,0	0,0	0,0	0,0	0,0
20%	100%	241.510	89,2	1,6	1,9	2,3	2,5	2,5
	90%	231.602	89,2	0,3	0,3	3,2	3,5	3,5
70%	100%	177.367	66,6	5,0	5,6	6,9	7,9	8,0
	90%	147.895	66,6	0,9	1,0	9,6	10,8	11,1

* reference situation
Source: OWN CALCULATIONS

The optimal crop management portfolios further include the choice of three fertilization intensities and irrigation. In the reference situation, high fertilization intensity (incl. irrigation) is applied on 26% and moderate fertilization intensity on 56% of the cropland. At 20% maize yield loss and 100% insecticide efficiency, the share of high fertilization intensity decreases by 24%, compared to the reference situation. At 70% maize yield loss and 100% insecticide efficiency, the share of high fertilization intensity (incl. irrigation) decreases by 36% whereas the shares of moderate and low fertilization intensities increase by 6% and 32% compared to the reference situation, respectively.

The adoption of alternative crop rotation systems leads to changes in crop distributions as well. For instance, grain sorghum area doubles at 20% maize yield loss and quintuples at 70% maize yield loss. Other crops which increase in area due to the reduction of maize shares in crop rotations are barley, soybean, faba beans and sunflowers (in decreasing order).

4. Summary and conclusions

The implementation of WCR control measures into crop management is crucial for the prevention of damages in maize production. Medium to high maize yield potentials are observed in several Austrian regions, which are thus susceptible to yield losses from WCR. If we assume a maize yield loss level of 70%, damages in terms of lower gross margins of more than 750 €/ha are possible in the South-East of Styria and on small cropland areas in other provinces. Considering pest control expenditures of 63 €/ha for a single insecticide application (max. two applications are allowed), median damage from WCR infestation of 216 €/ha at 20% maize yield loss and 755 €/ha at 70% maize yield loss is significant for farmers, because damage exceeds the costs of damage prevention. A relatively low adoption of maize crop rotations combined with insecticide applications in the model stresses the importance of efficient pest management options such as crop rotation adjustments. Besides, efficient insecticide applications are unlikely due to WCR development characteristics and application restrictions. The results reveal that the adoption of alternative crop rotation systems is often combined with reduced fertilization intensities and related agri-environmental payments.

A decrease in maize production challenges livestock producers and the processing industry. The potential of feed substitutes in diets should be addressed carefully when crop rotations are diversified. Regional heterogeneity in maize production and WCR infestation potentials should be addressed in developing specific WCR control measures. If a regional concentration of high damage is observed, this region may benefit from comprehensive WCR management. Investigated WCR control measures can be extended by alternative crops, crop management options, chemical and biological pest control measures. Finally, continuous monitoring can provide decision support in crop management.

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References

AWI (BUNDESANSTALT FÜR AGRARWIRTSCHAFT) (2016): IDB Deckungsbeiträge und Kalkulationsdaten. Online at: www.awi.bmlfuw.gv.at/idb (27.04.2016).

BMLFUW (2015): INVEKOS-Datenpool. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna.

GUGGENBERGER, T., HOFER, O., FAHRNER, W., SUCHER, B., WIEDNER, G. and BADER, R. (2012): Fachatlas Landwirtschaft - Entwicklung landwirtschaftlicher Geodaten im Geographical Grid System Austria. Veröffentlichungen HBLFA Raumberg-Gumpenstein, Band 49.

LK STEIERMARK (2016): Personal communication (21.6.2016).

MITTER, H., SCHMID, E. and SINABELL, F. (2015): Integrated modelling of protein crop production responses to impacts of climate change and agricultural policy scenarios in Austria. Climate Research 65, 205-220.

OERKE, C. (2006): Crop losses to pests. Journal of Agricultural Science, 144, 31-43.

SCHMID, E. and SINABELL, F. (2005): Using the Positive Mathematical Programming Method to Calibrate Linear Programming Models. Discussion Paper DP-10-2005, Institute for Sustainable Economic Development. Vienna: University of Natural Resources and Life Scienes.

SCHÖNHART, M., SCHMID, E. and SCHNEIDER, U. A. (2011): CropRota – A crop rotation model to support integrated land use assessments. European Journal of Agronomy 34, 236-277.

SINABELL, F., KAPPERT, R., KAUL, H.-P., KRATENA, K. und SOMMER, M. (2014): Maisanbau in Österreich. Ökonomische Bedeutung und pflanzenbaulicher Herausforderungen. WIFO, Vienna.

STRAUSS, F., FORMAYER, H. und SCHMID, E. (2013): High resolution climate data for Austria in the period 2008-2040 from a statistical climate change model. International Journal of Climatology 33, 430-443.

STÜRMER, B., SCHMIDT, J., SCHMID, E. and SINABELL, F. (2013): Implications of agricultural bioenergy crop production in a land constrained economy – The example of Austria. Land Use Policy 30, 570-581.

VERSUCHSREFERAT STEIERMARK (2016): Personal communication (10.6.2016).

WILLIAMS, J. R. (1995): The Epic model. in: SINGH, V.P. (Ed.): Computer models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, 909-100.

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