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Modelling crop rotation regulations to control western corn rootworm infestation under climate change in Styria

Modellierung von Fruchtfolgestrategien zur Regelierung des westlichen Maiswurzelbohrers unter Berücksichtigung des Klimawandels in der Steiermark

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Summary

The Western Corn Rootworm (WCR) has become a major maize pest in Austria. We analyze whether maize restrictions in crop rotations constitute a cost-effective strategy for controlling WCR infestation in Styria under climate change. Hence, we have developed an integrated modelling framework by linking a statistical climate change model, a crop rotation model, the bio-physical process model EPIC, the bottom-up land use optimization model BiomAT, and a statistical WCR model at 1 km spatial resolution. Model results reveal that reduced maize shares in crop rotations result in lower net returns in most regions, but can reduce WCR infestation considerably. The presented analysis may inform the design of WCR policies and control strategies.

Keywords: integrated land use modelling, Western Corn Rootworm, pest abundance modelling, climate change, crop rotation

Zusammenfassung

Der Westliche Maiswurzelbohrer (WMB) hat sich in den letzten Jahren zu einem bedeutenden Schädling im österreichischen Maisanbau entwickelt. Wir untersuchen, inwieweit eine Beschränkung des Maisanteils in der Fruchtfolge zur Regulierung des WMB in der Steiermark und unter sich verändernden Klimabedingungen beitragen kann. In einem integrierten Modellverbund kombinieren wir ein statistisches Klimamodell, ein Fruchtfolgemodell, das bio-physikalische Prozessmodell EPIC, das ökonomische Landnutzungsoptimierungsmodell BiomAT und ein statistisches WMB Auftrittsmodell mit 1 km räumliche Auflösung. Die Modellergebnisse zeigen, dass die Reduktion des Maisanteils in der Fruchtfolge in manchen Regionen zu niedrigeren Deckungsbeiträgen führt. Gleichzeitig zeigen sie einen wesentlichen Rückgang des WMB Befalls. Der dargestellte Ansatz kann Entscheidungsträger bei der Einführung von Maßnahmen zur Kontrolle des WMB unterstützen.

Schlagworte: Integrierte Landnutzungsmodellierung, Westlicher Maiswurzelbohrer, Schädlingsauftrittshäufigkeit, Klimawandel, Fruchtfolge

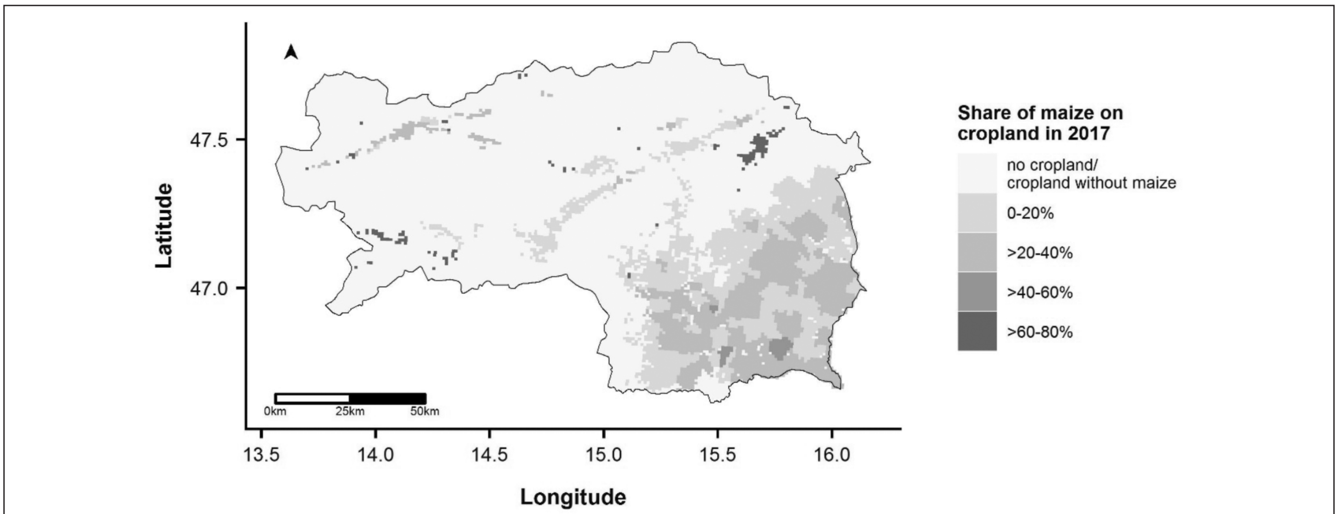
1 Introduction

Invasive pests and climate change may have severe ecological and economic impacts on agricultural production (Aragón and Lobo, 2012). Pests are closely linked to their host plants and to climate conditions (Diffenbaugh et al., 2008). Thus, understanding the interaction between pests and their habitat as well as the spread mechanisms is crucial for developing effective control strategies (Dillen et al., 2010). In Austria, the highly mobile Western Corn Rootworm (WCR; *Diabrotica virgifera virgifera*) is an invasive pest. Its continuous spread and damage potential constitute a key challenge for maize production. Climate conditions and maize shares in crop rotations are assumed to be among the most important factors influencing WCR spread and abundance (Falkner et al., 2019). In Austria, WCR infestation has been monitored via pheromone traps since its first detection in 2002. Monitoring data confirm WCR spread across Austria. Therefore, it is important to develop management strategies and policy regulations to slow down WCR spread and abundance. Particularly, crop rotations with low maize shares are deemed an effective control strategy (Aragón et al., 2010; Meinke et al., 2009). Some Austrian provinces have already established crop rotation regulations limiting maize cultivation frequencies on fields.

Maize is a major crop in some Austrian agricultural production regions due to its favorable cropping characteristic, i.e. the low work effort, the self-compatibility and low requirements on crop rotations as well as its versatile use. One of these maize intensive production regions is the Austrian province of Styria. In Styria, climate conditions are favorable for maize production and yield potentials are among the highest in the world (Sinabell et al., 2015). Figure 1 shows the maize shares on total cropland per cropland grid cell (1 km) in Styria, which are highest in the south-eastern part. Styrian farmers are particularly dependent on maize production for livestock feeding. Furthermore, they are susceptible to yield losses and therefore economic losses from WCR infestation, but simultaneously the above mentioned crop rotation regulations oblige them to switch to lower yielding crops. The Styrian crop rotation regulation allowed maize cultivation in three out of four years, i.e. 75% maize in crop rotations until 2016. In 2017 and 2018, maize was allowed to be cultivated twice in succession at most, i.e. 66% maize in crop rotations (Stmk. LGBl. Nr. 32/2015, 2015). Many farmers expected higher economic losses from a more restrictive crop rotation regulation than from WCR infestation. In 2019, the Styrian crop rotation regulation was repealed and crop rotations may consist of 75% maize at maximum (Stmk. LGBl. Nr. 14/2019, 2019).

Different types of models have been developed to identify regions of WCR invasion and analyze the WCR damage potential. For instance, Aragón et al. (2010) use a niche modelling technique for identifying the potential geographic range of WCR in Europe and producing risk maps. Dillen et al. (2010) use a bio-economic model for an economic assessment of damage abatement strategies against WCR in Hungarian maize production. Feusthuber et al. (2017) apply a spatially explicit modelling framework to calculate WCR damage potentials from maize yield losses and to determine efficient crop management strategies considering insecticide application, fertilization intensities, irrigation and crop rotations. They identified crop rotation regulations to be an effective WCR control strategy. However, these studies do not evaluate both the economic effect of crop rotational restrictions and their effectiveness to control WCR. We refer to the WCR model developed by Falkner et al. (2019) and estimate the probability of WCR occurrence and WCR abundance on Styrian cropland as a function of climate conditions and the maize share in crop rotations. We apply the model within an integrated modelling framework (IMF, see section 2) to assess the effect of crop rotation regulations with maize restrictions on (i) net returns and dry matter crop yields, and (ii) the probability of WCR occurrence and WCR abundance under climate change. Section 3 presents the results of the analysis, which are discussed and summarized in section 4.

Figure 1: Maize shares on cropland per cropland grid cell of 1km in Styria (Source: Own illustration based on AWI and BMNT, 2018).



2 The integrated modelling framework

We apply a spatially explicit integrated modelling framework (IMF) to assess the effectiveness of crop rotation regulations with limited maize shares on reducing WCR infestation under climate change scenarios. A similar IMF has inter alia been applied by Mitter et al. (2015a and b) and Kirchner et al. (2015). The main extension in our analysis refers to a WCR model estimating the probability of WCR occurrence and WCR abundance on cropland (Falkner et al., 2019).

Climate change scenarios for a future period (2010-2040) are derived from the statistical climate change model ACLiReM (Austrian Climate change Model using Linear Regression; Strauss et al., 2013). Based on historical weather station data, ACLiReM provides daily weather data with a rising temperature trend of approximately 0.05°C per year. Daily precipitation sums are assumed to resemble the past (SIMILAR) or change by ±20% (WET, DRY), compared to the past (1975-2005). The crop rotation model CropRota (Schönhart et al., 2011) is applied to derive typical crop rotations at municipality level based on observed land use data provided by the IACS database (EU Integrated Administration and Control System (BMLFUW, 2017) and expert knowledge. A baseline crop rotation and mutually explicit alternative crop rotations with upper limits for maize shares set to 50%, 25% and 10% are developed at 1 km resolution. Grain sorghum and other cereals are considered as main substitutes for maize in the alternative crop rotations.

The bio-physical process model EPIC (Environmental Policy Integrated Climate; Williams, 1995) simulates soil-crop-management-climate interactions and processes at a spatial resolution of 1 km. It provides outputs on, inter alia annual crop yields and agro-environmental outcomes (e.g. nitrogen emissions). Daily weather data from the ACLiReM climate scenarios, soil and topographic data as well as the modelled crop rotations are input to EPIC. We further consider four management variants, which comprise three crop dependent fertilizer application levels high, moderate and low under rainfed conditions and irrigation combined with high fertilization intensity.

Simulated crop yields are used to calculated annual crop gross margins using variable production costs, agricultural commodity prices and policy premiums form the Standard Gross Margin Catalogue (AWI, 2016). It should be noted here that we do not account for costs of insecticide application or yield losses from WCR damages. Crop gross margins feed into a non-linear version of the agricultural optimization model BiomAT (bottom-up agricultural land use optimization model for Austria; Feusthuber et al., 2017; Karner et al., 2018; Stürmer et al., 2013). BiomAT is spatially explicit and maximizes total net returns from crop production by optimizing cropland use and management subject to cropland endowments at 1 km grid resolution. BiomAT is calibrated to past climate conditions and the baseline crop rotation by using a Positive Mathematical Programming (PMP) approach (Howitt, 1995). The calibrated BiomAT model is used for policy analysis, i.e. for investigating the effects of crop rotational restrictions with maize shares limited to 50% (MS50), 25% (MS25) and 10% (MS10) at maximum, respectively.

The statistical WCR model (Falkner et al., 2019) is used to analyze WCR spread and abundance on Styrian cropland. The model is calibrated to WCR monitoring data, i.e. WCR counts from pheromone traps on cropland between 2013 and 2015 (AGES, 2008), site-specific climate conditions (ZAMG, 2018) and maize shares in crop rotations (AWI and BMNT, 2016). Using a zero-inflated Poisson mixture model, which combines a Bernoulli and a Poisson model, acknowledges that WCR monitoring data are zero-inflated. The former is used to model the probability of WCR occurrence, i.e. the probability of WCR infestation, as a function of WCR's natural spread, represented by latitude and longitude and the maize share in a particular region. The latter is used in case of WCR infestation for modelling WCR abundance, which allows for zero counts in infested regions and is assumed to be additionally influenced by climate conditions which are assumed to affect the life cycle stage of WCR development(see e.g., Toepfer and Kuhlmann, 2005). By using kriging, i.e. a geo-statistical interpolation method considering spatial autocorrelation, the probability of WCR occurrence and WCR abundance are modelled for total Styrian cropland. We apply the calibrated WCR model to the optimized crop rotational regulations with varying upper limits for maize, derived from BiomAT and three climate scenarios (SIMILAR, WET, DRY) to estimate WCR spread and abundance for total Styrian cropland under climate change at 1 km grid resolution.

3 Results

3.1 Maize area under crop rotational restrictions and climate change scenarios in Styria

In the baseline crop rotation (BASE), reflecting reported crop shares from the past, maize is the predominant crop in Styria and produced on 59,100 ha or 44.5% of the total cropland. Thereof, 23,100 ha are cultivated in crop rotations consisting of more than 75% maize. Such maize intensive crop rotations are mainly located in south-eastern Styria (Figure 1). Maize areas remain under WET climate conditions but decrease under DRY climate conditions by 8.4% to 54,200 ha. With crop rotational restrictions, total maize area declines under SIMILAR climate conditions by about 23.0% (45,600 ha), 52.8% (27,900 ha), and 80.0% (11,800 ha), respectively. The maize areas change similarly under WET and DRY climate conditions.

Maize substitutes mostly include cereals. In BASE, for instance, grain sorghum is cultivated on about 5,000 ha and its cultivation area almost doubles in MS50, triples in MS25 and quadruples in MS10. The results also show that grain sorghum gains more in importance under DRY climate conditions.

3.2 Crop production and net returns under crop rotational restrictions and climate change scenarios

In BASE, crop production in Styria generates a total net return of 43.6 Mio. € from a total dry matter crop yield of 1.1 Mio. t. The annual net returns on cropland grid cells vary between 73 €/ha and 749 €/ha with an average of 323 €/ha across Styria. Dry matter crop yields vary between 2.7 t/ha and 16.3 t/ha with an average of 8.1 t/ha. Table 1 presents the area-weighted average annual net returns (in €/ha) and dry matter crop yields (in t/ha) with standard deviations for the baseline and the alternative crop rotation scenarios. Compared to BASE, MS50 entails a decreasing total and average net return by 3.7% to 42.0 Mio. € and 311 €/ha under SIMILAR climate conditions, respectively. The total dry matter crop yield decreases by 4.2% to 1.05 Mio. t and the average dry matter crop yield also decreases by 4.2% from 8.1 t/ha to 7.8 t/ha (SIMILAR). Total and average net returns and dry matter crop yields further decrease under the more restrictive crop rotational restriction MS25 and MS10. The model results also show a higher standard deviation with more restrictive crop rotation regulations for both, net returns and dry matter crop yields. This implies that the spatial variation in net returns and dry matter crop yields increases. Furthermore, changing climate conditions (WET and DRY) negatively affect net returns in BASE and MS50. In MS25 and MS10, DRY climate conditions result in a higher average net return compared to SIMILAR, whereas the average net return under WET climate conditions is lower compared to SIMILAR. In contrast, average dry matter crop yields remain similar under WET climate conditions and decrease slightly under DRY climate conditions under all crop rotational restrictions.

3.3 WCR infestation under crop rotational restrictions and climate change scenarios

Our analyses show a high probability of WCR occurrence for the future period for total cropland in Styria, independently of the considered crop rotational restriction or climate change scenario. This high probability of WCR occurrence can be explained by the high WCR count values in the monitoring data, indicating that WCR has already established on Styrian cropland. However, the estimated WCR abundance varies spatially. The results for BASE under SIMILAR climate conditions (Figure 2a) show that WCR abundance is modelled to be high on 42.6% (57,600 ha) of cropland. Modelled moderate or low WCR abundance amounts to 51.1% (69,000 ha) and 6.3% (8,500 ha). The effect of crop rotational restrictions on WCR abundance under SIMILAR climate conditions is shown in Figure 2b-d. For instance, in MS50 the modelled high WCR abundance area decreases to approximately 37,500 ha, which constitutes 27.7% of cropland in Styria. In MS25 (MS10), the modelled high abundance area is 6,000 ha (1,300 ha) amounting to 4.4% (1.0%) of cropland. The described effect of crop rotational restrictions on WCR abundance, i.e. the decrease in the modelled high WCR abundance area also applies under WET and DRY climate conditions. However, the model results show that WET climate conditions are more favorable for WCR abundance than SIMILAR climate conditions, i.e. high and moderate WCR abundance is modelled for more cropland under all crop rotational restrictions. For instance, the modelled high WCR abundance area in BASE amounts to about 66,100 ha (48.9%), even though the maize area decreases. In MS10, the high WCR abundance area (2,700 ha) more than doubles compared to SIMILAR climate conditions. This indicates a positive influence of increasing precipitation sums in summer in combination with increasing temperatures on WCR abundance (Falkner et al., 2019). The model results also show that DRY climate conditions are less favorable for WCR development than SIMILAR climate conditions, as the modelled WCR abundance is lower under all crop rotational restrictions. Hence, the model results show that the reduction of the maize share in crop rotations can be an effective strategy to control WCR spread and abundance in Styria under all climate change scenarios.

4 Discussion and conclusion

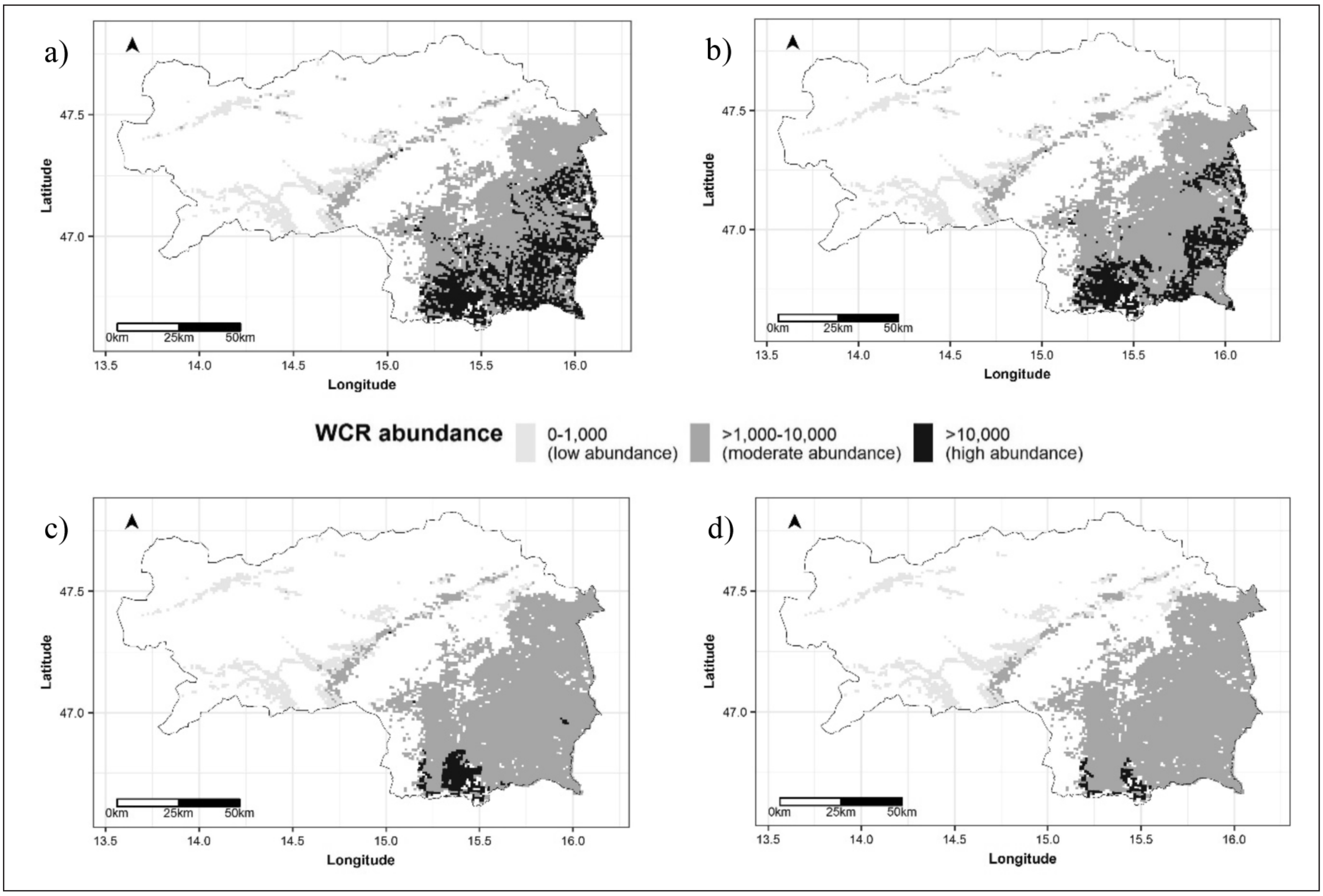
WCR invasion constitutes a key challenge for maize production regions with high maize yield potentials, such as in Styria. Successful WCR infestation and spread depend mainly on the availability of maize and climate conditions.

Table 1: Area-weighted average annual net returns (in €/ha) and dry matter crop yields (in t/ha) with standard deviations (in brackets) for the basline and three levels of crop rotational restrictions under climate change in Styria.

	BASE		MS50		MS25		MS10	
Climate scenario	Net return	Crop yield	Net return	Crop yield	Net return	Crop yield	Net return	Crop yield
SIMILAR	322.81	8.1	310.76	7.8	269.84	7.3	198.63	6.8
	(72.15)	(1.47)	(74.79)	(1.44)	(88.59)	(1.57)	(98.89)	(1.61)
WET	309.30	8.1	297.55	7.8	257.03	7.4	184.93	6.9
	(74.24)	(1.52)	(77.75)	(1.52)	(93.92)	(1.65)	(104.93)	(1.71)
DRY	309.25	7.7	302.48	7.4	269.96	7.1	208.90	6.6
	(82.15)	(1.38)	(83.72)	(1.33)	(90.32)	(1.41)	(97.32)	(1.43)

Source: Own calculations.

Figure 2: WCR abundance maps for a) the BASE crop rotation, and crop rotational restrictions b) MS50, c) MS25 and d) MS10 under SIMILAR climate conditions (Source: Own illustration based on model results).



Therefore, it is crucial to design management and policy measures that help to reduce WCR infestation and spread and thus prevent major maize damages and economic losses. We have assessed the effect of crop rotational restrictions on net returns, dry matter crop yields, and WCR abundance with different climate change scenarios by applying an IMF. The model results show that crop rotational restrictions with upper limits for maize shares result in decreasing net returns and dry matter crop yields. Declining net returns mainly occur on cropland areas where the maize restrictions become effective. However, we do not account for maize yield losses from WCR infestation or costs for pesticide application. Hence, the reduction in net returns and dry matter crop yields is the sole effect of crop rotational restrictions, i.e. our approach does not allow assessing the positive effect of lower WCR abundance due to crop rotational regulations on net returns and dry matter crop yields. Feusthuber et al. (2017) show that maize yield losses from WCR infestation can considerably decrease net returns, especially in maize intensive production regions. For instance, according to their results an assumed yield loss of 10% causes an average reduction of net returns by 49 €/ha on a national level. In this analysis we would also expect crop rotational restrictions to be efficient for controlling WCR if losses from WCR infestation or costs for pesticide application are considered in BASE.

The WCR abundance maps show that the crop rotational restrictions can help to lower WCR spread and abundance independently of the considered climate change scenario. Therefore, the effect of climate change is limited compared to the effect of crop rotational restrictions.

However, our approach has some limitations. The increase in the standard deviations of net returns and dry matter crop yields under crop rotational restrictions indicates that maize has a smaller variability than alternative crops and that crop rotational restrictions might present an income risk for farmers, especially if they are dependent on maize production, e.g. for feeding livestock. Therefore, it is important to consider regional characteristics and substitutes in livestock diet for developing successful WCR control measures. Furthermore, we would expect legally binding crop rotational restrictions to cause high opportunity costs in regions which are not facing WCR problems. Future research should focus on the development and analysis of region-specific crop rotational restrictions.

Continuous WCR monitoring can provide useful data and information for early determination of WCR pressure. This might help to apply complementary WCR control strategies early in the season. In case of regionally high WCR pressure, the investigated crop rotational restrictions can be extended by alternative crop or soil management options as well as by chemical or biological measures. Finally, the enhancement of communication between farmers and the application of collective measures, such as regionally coordinated crop rotations, may help to control hotspots of WCR occurrence and thus facilitate WCR management.

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References

AGES(2008) Maiswurzelbohrer. AGES – Österr. Agent. Für Gesundh. Ernährungssicherheit. URL https://www.ages.at/themen/schaderreger/maiswurzelbohrer/ (1.24.17).

Aragón, P., Baselga, A. and Lobo, J. M. (2010) Global estimation of invasion risk zones for the western corn rootworm Diabrotica virgifera virgifera: integrating distribution models and physiological thresholds to assess climatic favourability. Journal of Applied Ecology 47, 5, 1026–1035. https://doi.org/10.1111/j.1365-2664.2010.01847.x

Aragón, P. and Lobo, J. M. (2012) Predicted effect of climate change on the invasibility and distribution of the Western corn root-worm. Agricultural and Forest Entomology 14, 1, 13–18. https://doi.org/10.1111/j.1461-9563.2011.00532.x

AWI (Bundesanstalt für Agrarwirtschaft)(2016) IDB Deckungsbeiträge und Kalkulationsdaten. URL https://idb.awi.bmlfuw.gv.at/idb (10.29.18).

AWI (Bundesanstalt für Agrarwirtschaft) und BMNT (Bundesministerium für Nachhaltigkeit und Tourismus) (2016) Gemeindedatenbank - GeDaBa 2016: Projekthandbuch. Wien.

BMLFUW (2017) INVEKOS Datenpool. Wien.

Diffenbaugh, N. S., Krupke, C. H., White, M.A. and Alexander, C. E. (2008) Global warming presents new challenges for maize pest management. Environmental Research Letters, 3, 044007. https://doi.org/10.1088/1748-9326/3/4/044007

Dillen, K., Mitchell, P. D. and Tollens, E. (2010) On the competitiveness of Diabrotica virgifera virgifera damage abatement strategies in Hungary: a bio-economic approach. Journal of Applied Entomology, 134, 5, 395–408. https://doi.org/10.1111/j.1439-0418.2009.01454.x

Falkner, K., Mitter, H., Moltchanova, E., and Schmid, E. (2019) A zero-inflated Poisson mixture model to analyse spread and abundance of the Western Corn Rootworm in Austria. Agricultural Systems 174, 105–116. https://doi.org/10.1016/j.agsy.2019.04.010

Feusthuber, E., Mitter, H., Schönhart and M., Schmid, E. (2017) Integrated modelling of efficient crop management strategies in response to economic damage potentials of the Western Corn Rootworm in Austria. Agricultural Systems 157, 93–106. https://doi.org/10.1016/j.agsy.2017.07.011

Howitt, R.E. (1995) Positive Mathematical Programming. American Journal of Agricultural Economics, 77, 2, 329. https://doi.org/10.2307/1243543

Karner, K., Mitter, H., Schönhart, M. and Schmid, E. (2018) The value of information for efficient agricultural adaptation to climate change scenarios in a semiarid region in Austria, in: Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues (Ed.) Agrar- Und Ernährungswirtschaft Zwischen Ressourceneffizienz Und Gesellschaftlichen Erwartungen: 57. Jahrestagung Der Gesellschaft Für Wirtschafts - Und Sozialwissenschaften Des Landbaues e.V. Vom 13. Bis 15. September 2017, Schriften Der Gesellschaft Für Wirtschafts- Und Sozialwissenschaften Des Landbaues e.V. Landwirtschaftsverlag GmbH, Münster, pp. 173–184.

Kirchner, M., Schmidt, J., Kindermann, G., Kulmer, V., Mitter, H., Prettenthaler, F., Rüdisser, J., Schauppenlehner, T., Schönhart, M., Strauss, F., Tappeiner, U., Tasser, E. and Schmid, E. (2015) Ecosystem services and economic development in Austrian agricultural landscapes — The impact of policy and climate change scenarios on trade-offs and synergies. Ecological Economics. 109, 161–174. https://doi.org/10.1016/j.ecolecon.2014.11.005

Meinke, L. J., Sappington, T. W., Onstad, D. W., Guillemaud, T., Miller, N. J., Komáromi, J., Levay, N., Furlan, L., Kiss, J. and Toth, F. (2009) Western corn rootworm (Diabrotica virgifera virgifera LeConte) population dynamics. Agricultural and Forest Entomology. 11, 1, 29–46. https://doi.org/10.1111/j.1461-9563.2008.00419.x

Mitter, H., Heumesser, C. and Schmid, E. (2015a) Spatial modeling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change. Land Use Policy 46, 75–90. https://doi.org/10.1016/j.landusepol.2015.01.010

Mitter, H., Schmid, E. and Sinabell, F. (2015b) Integrated modelling of protein crop production responses to climate change and agricultural policy scenarios in Austria. Climate Research 65, 205–220. https://doi.org/10.3354/cr01335

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, 4, 263–277. https://doi.org/10.1016/j.eja.2011.02.004

Sinabell, F., Kappert, R., Kaul, H.-P., Kratena, K. und Sommer, M. (2015) Maisanbau in Österreich: Ökonomische Bedeutung und pflanzenbauliche Herausforderungen 97.

Stmk. LGBl. Nr. 14/2019 (2019) Verordnung der Steiermärkischen Landesregierung vom 7. Februar 2019 betreffend die Bekämpfung des Maiswurzelbohrers.

Stmk. LGBl. Nr. 32/2015 (2015) Verordnung der Steiermärkischen Landesregierung vom 30. April 2015, mit der die Maiswurzelbohrerverordnung 2015 geändert wird.

Strauss, F., Formayer, H. and 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, 2, 430–443. https://doi.org/10.1002/joc.3434

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. https://doi.org/10.1016/j.landusepol.2012.04.020

Toepfer, S. and Kuhlmann, U. (2005) Natural mortality factors acting on western corn rootworm populations: a comparison between the United States and Central Europe. In: Vidal, S., Kuhlmann, U. and Edwards, C. R. (Eds.), Western Corn Rootworm: Ecology and Management. CABI Pub, Wallingford, Oxfordshire, UK, 95–120.

Williams, J.R., 1995. The EPIC Model. Comput. Models Watershed Hydrol. 909–1000.

ZAMG (2018) INCA: Integrated Nowcasting through Comprehensive Analysis. INCA Integr. Nowcasting Compr. Anal. URL http://www.zamg.ac.at/cms/de/forschung/wetter/inca