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Developing a decision support tool to forecast the abundance of the cabbage stem weevil in winter oilseed rape

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Abstract: Reducing the use of pesticides in agricultural systems is a prerequisite for sustainable agriculture and, therefore, knowledge on the factors that influence the regional insect pest densities is necessary. Based on multi-site and multi-annual observations of the cabbage stem weevil [*Ceutorhynchus pallidactylus* (Marsham, 1802)] in winter oilseed rape (*Brassica napus* Linnaeus) and the corresponding meteorological measurements, a statistical relationship for forecasting the abundance was derived. The model explains 84% of the variation of the data set. The remaining 16% might be explained by the landscape effects and agricultural practices, such as crop protection. Based on the statistical relationship between the mean winter air temperature and the abundance of the cabbage stem weevil in the winter oilseed rape, risk maps were derived as a forecast tool for practical farming.

Keywords: *Ceutorhynchus pallidactylus*; forecast system; *Brassica napus*; risk maps; yellow water trap

Due to the EU directive 2009/128/EC on the sustainable use of pesticides, decision support systems (DSSs) are highly recommended for agricultural crops (Damos 2015; Lefebvre et al. 2015). So far, most of the available DSSs for insect pests are forecasting the date of migration in the respective host plants, e.g., Klueken et al. (2009), Eickermann et al. (2014a). Also, methodical approaches to advise on using the accurate timing of a pesticide application exist, e.g., Ferguson et al. (2015). So far, models capable of predicting the abundance of insect pest species are still missing, as well as simple tools providing such information to farmers. Especially, winter oilseed rape (WOSR) (*Brassica napus* Linnaeus) is threatened by a large number of different pest insects during the season (Williams 2010). The cabbage stem weevil [*Ceutorhynchus pallidactylus* (Marsham, 1802)] (Coleoptera: Curculionidae) appears all over Europe causing substantial yield losses (Juran et al. 2011; Spitzer et al. 2014). A detailed overview on its biology is given by Williams (2010). The species is univoltine and the adults overwinter in the litter surface in the woods close to the agricultural fields. In March, the adults migrate to the crops and females, shortly after copulation, start oviposition in the petioles of the WOSR during the stem elongation of the plants. The larvae of *C. pallidactylus* mine at the stem piths from April to May. After the third instar, the larvae migrate to the soil for pupation. At the beginning of July, young adults hatch from their cocoons in the soil and feed on other brassicaceous plants before the diapause. Farmers can easily detect the number of stem weevils by using yellow water traps (Williams 2010). When more than 10 weevils per trap within three consecutive days are observed, a chemical control is recommended (Eickermann et al. 2015). Since

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insect resistant cultivars of WOSR are not available, the application of insecticides is still a common practice (Eickermann & Ulber 2010; Hervé 2017).

Forecast models were developed for this pest species (Junk et al. 2012; Klem & Spitzer 2017), mainly based on meteorological variables, like the air and soil temperature. Models are predicting the migration to WOSR crops. Additionally, a model has been developed to predict if the economical threshold for *C. pallidactylus* will be breached in the following season. This model is based on the analysis of the mean air temperature in February – and allows for the early prediction whether a high or low number of individuals will occur in the upcoming season (Eickermann et al. 2015). Up to now, no practical application for the use of this model by farmers exists. Therefore, we developed a risk map approach for an easy visualisation offering farmers precise predictions for their individual fields.

MATERIAL AND METHODS

Insect monitoring. Based on a long-term field-monitoring programme in Luxembourg, data on pests in WOSR based on yellow water traps were available for *C. pallidactylus* at five test sites, at Obercorn (313 m a.s.l.), Burmerange (222 m a.s.l.), Everlange (307 m a.s.l.), Christnach (313 m a.s.l.) and Reuler (472 m a.s.l.) (Figure 1). Six yellow traps (30 × 30 × 15 cm) were installed per field at a distance of 15 m from the field edge, where no insecticides were applied during the season. Each trap was filled with 2 litres of tap water and a surfactant was added (» 0.2 mL) to break the surface tension of the water. The sampled insects were transferred to ethanol (70%) and identified by using keys given by Alford et al. (2003). Based on the ground surface of the trap, the number of *C. pallidactylus* individuals were calculated per square meter. More details on the monitoring programme are given in Eickermann et al. (2013), a description of the long-term meteorological characteristics for these sites are described in Eickermann et al. (2014b).

The yellow traps were checked twice per week. The number of *C. pallidactylus* individuals collected at each location and year were classified into three categories: (*i*) the number of weevils below the control threshold (< 11 individuals), (*ii*) the number of weevils slightly above the control threshold (11 to 30 individuals) and (*iii*) the number of weevils greatly exceeding the control threshold (> 30 individuals).

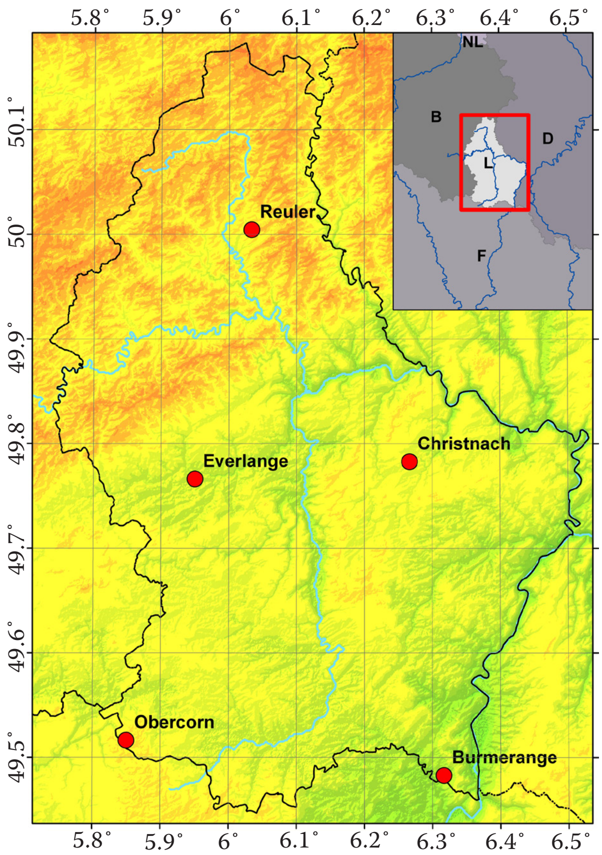

Figure 1. Locations of the meteorological stations used in the study and the digital elevation model (resolution 2 m)

For the statistical analysis, a leave one out cross-validation, as described by Witten et al. (2011), and used in agriculture applications by Beyer et al. (2012) was applied, in order to verify the quality of the forecast model.

Meteorological measurements. The necessary meteorological variables – identified by Eickermann et al. (2015) – for developing the risk maps, were retrieved from the data repository of the official agricultural service of Luxembourg (Administration des Services Technique de l'Agriculture). Measurements were taken at 1-minute resolution and the 10-min mean values were stored for the later analysis. The meteorological time-series was pre-processed based on an automatic data processing chain for gap detection, quality and plausibility checking (Junk et al. 2016). Gap filling via interpolation was applied to the 2% of the missing raw data.

The mean air temperatures were calculated for the period from February 5th till 13th for the years 2007 to 2016 for each of the 34 automatic weather stations. This time period has been identified by Eickermann et al. (2015) as significantly affecting the abundance

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of following season. The breaching of the economic threshold for the cabbage stem weevil can be expected if the mean winter temperatures between February 5th to 13th come closer to 4.0 °C than to –2.4 °C.

Statistics and development of the risk maps. A spatial interpolation approach for the meteorological data was used to obtain regional information on the spread and the abundance of the cabbage stem weevil in Luxembourg. The point data of the air temperatures at the 34 stations were interpolated using the spatial analysis tool of the software package ArcGIS (version 10.0) to create spatial maps. The interpolation method "kriging" was used, whereat the autocorrelation among the measurements is taken into account (Venäläinen & Heikinheimo 2002).

RESULTS

The breaching of the economic threshold for the cabbage stem weevil can be expected if the mean winter temperatures between the 5th and 13th of February are closer to –2.4 °C than to 4.0 °C. The correlation between the average air temperature and the maximum number of weevils per yellow trap within three consecutive days is given in Figure 2. With an increase in the mean air temperature in the respective time-span in February, the risk of breaching the control threshold is getting lower. The model explains 84% of the variation of the yellow trap data sets. Especially in 2012, a very high number of *C. pallidactylus* individuals was found in the yellow traps in March due to the low temperature in the respective time-span during the previous February.

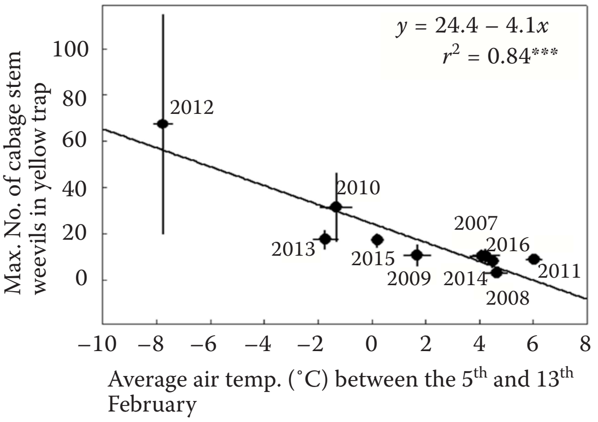

Figure 2. Scatterplot of the maximum number of weevils in the yellow traps within three days and the average air temperature in the period between the 5th and 13th of February for the years 2007–2016

Examples of the visualisation of the mean winter air temperatures for the period from the 5th until the 13th of February and recommendations for the potential chemical control of *C. pallidactylus* are given in Figure 3. Cases from 3 years (2008, 2010, and 2013) with contrasting meteorological conditions were chosen for the detailed discussion. Information for the remaining years is given in Figure 2.

In 2008, the air temperature in Luxembourg for the respective period of time was in a positive range. Therefore, no treatment recommendation was indicated through the model. This forecast was validated by the number of individuals observed in the yellow water traps (locations indicated by green stars in Figure 3A). For each test site, the recommendation of the model was proofed by the monitoring programme. In 2010, slightly lower air temperatures were observed during the first part of February. Therefore, a breaching of the control threshold was forecasted by our model (yellow and red stars in Figure 3B), and again validated through the monitoring programme. A higher number of individuals in the southern part of Luxembourg (Obercorn and Bumerange) was detected by the monitoring programme compared to the northern sites in 2010. Finally, in Figure 3C, an example with high winter air temperatures in 2016 is given. The model suggests no chemical control method for the whole country, whereas the monitoring programme detected the breaching of the control threshold at one test site in the south of Luxembourg (Burmerange). While *C. pallidactylus* is a univoltine species, it is necessary to get information on the abundance of the accumulated number of individual pests throughout the season that influence the population density in the following season. Therefore, the number of individual pests was monitored in addition during the whole monitoring programme (2007 till 2016). Corresponding to Figure 3, the abundance of the weevil population was presented for 2008, 2010 and 2016 (Figure 4).

In the year 2008 (under relatively warm conditions), the model recommended no chemical treatment for controlling *C. pallidactylus* because the threshold was not reached. The field observations by the yellow traps showed a low number of accumulated individuals at all sites over the whole season – highly corresponding with the model forecast – were observed (Figure 4).

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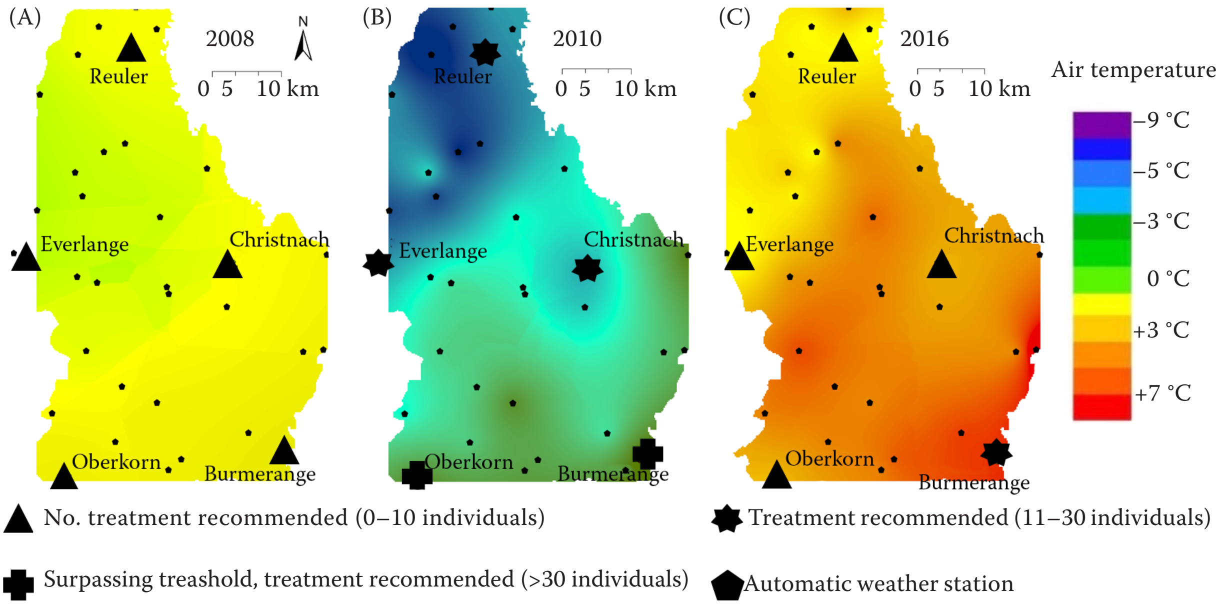

Figure 3. Visualisation of the winter air temperatures recorded by 34 automatic weather stations for the period from the 5th until 13th of February and the treatment recommendations for *C. pallidactylus* based on the yellow trap data sets for the selected years (A) 2008, (B) 2010 and (C) 2016 for Luxembourg

On the contrary, in 2010, a low winter air temperature occurred, leading to the chemical control recommendation by the model. Especially at Burmerange and Obercorn (red stars, Figure 3B), more than 1 000 weevils were caught per square meter (Figure 4), At the other three experimental sites, lower numbers were detected, but still at a level of an economic impact.

In 2016, no chemical control was recommended due to the high mean air temperatures in the previous

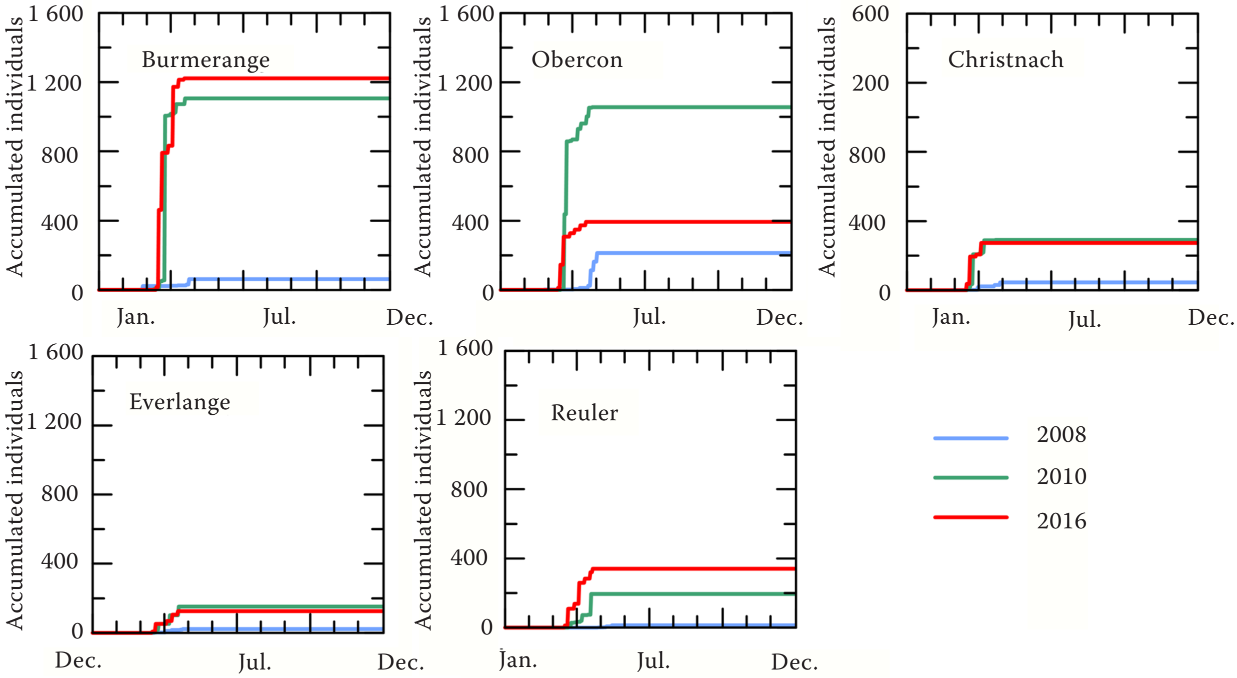

Figure 4. Progress of the accumulated number of *C. pallidactylus* individuals per square meter based on the yellow water trap data sets for the five observational sites in Luxembourg

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February (green stars, Figure 3C). An exception is the test site at Burmerange in the south of the country, where the number of accumulated individuals per square meter was extremely high (> 1 200 individual) (Figure 4).

DISCUSSION

The presented results can forecast if the economic threshold for the cabbage stem weevil, *C. pallidactylus*, in oilseed rape fields will be breached based on the winter air temperatures four weeks before the insects migrate to the fields. The information was transferred into a visual forecast tool for a regional DSS for the first time. It has been demonstrated that the low winter air temperatures in the period from the 5^{th} to the 13^{th} of February will lead to higher a number of *C. pallidactylus* individuals in the following springtime (Eickermann et al. 2015; Klem & Spitzer 2017). Overwintering in diapause in wooded areas at the forest edges at a low winter air temperature guarantees the immobility of the individuals, whereas comparable high air temperatures lead to the awakening of the insects and, therefore, a higher mobility rate. This finally leads to starvation due to the lack of nutrients. Mechanisms like the accumulation of energy reserves in combination with a significantly released rate of metabolism were quite often observed for the univoltine insect species, mostly in combination with an obligate diapause (Bale et al. 2002; Hahn & Denlinger 2011).

An early forecast of weevil abundance is beneficial for the farmers to prevent any unnecessary monitoring efforts. Monitoring relies on the number of individuals caught in the yellow water trap (Schütte 1970). For Luxembourg, the value of > 10 weevils per trap is used as a robust indicator to monitor the pest species abundance in WOSR.

The time series presented in Eickermann et al. (2015) was extended in this study by four years of additional field observations and the statistical relationship was confirmed (Figure 2). The outputs of the forecast model for the test sites were transferred into maps (Figure 3). The data sets of the long-term field monitoring of the cabbage stem weevil were then used to validate the model forecasts.

In 2008, warm winter air temperatures led to low number of observed individual pests, also predicted by the model. In 2010, the winter air temperature led to a high number of individuals all over the country, but with a significantly higher number of weevils at Burmerange and Obercorn compared to the other stations. It could be expected that the high acreage of oilseed rape during this season led to an increased abundance of the cabbage stem weevil. Additionally, both sites were located in the vicinity of sheltered areas for overwintering in 2010. The landscape effects on the pest insects in WOSR were recently described in literature (e.g., Zaller et al. 2008; Rusch et al. 2013). *C. pallidactylus* is fairly stationary and prefers only short distance flights (Moser et al. 2009). Therefore, WOSR fields in neighbouring wooded areas offer higher levels of the weevil's abundance (Zaller et al. 2008). In 2016, higher temperatures were measured in the specific time-span in February leading to a low number of weevils in the yellow traps. This was forecasted by the model (Figure 2) and was quite comparable to 2007 and 2014. Therefore, no application of insecticide was recommended. The test site Burmerange in the south of the country was an exception in 2016, where the number of individuals was extremely high. It could be expected that the micro-climate of the overwintering habitat led to a decreased level of winter mortality at this test site, but knowledge about the pre-requisites for overwintering of *C. pallidactylus* is limited. There is no knowledge about the nutrition level of adult weevils for successful overwintering. Also, the cold hardiness was never recorded in detail for *C. pallidactylus*. This species shares the same ecological niche with the pollen beetle, *Brassicogethes aeneus* (Fabricius, 1775) (Juhel et al. 2017). Sheltered areas offer less temperature fluctuations by a thick litter layer, which could be preferred for overwintering by both species. Additionally, adult specimens of the pollen beetle and cabbage stem weevil select microhabitats that offer a low risk of flooding through winter precipitation (Rusch et al. 2012). Landscape effects are of major influence to insect pests in WOSR, and, therefore, can interact with the abundance of *C. pallidactylus* (Rusch et al. 2013). Additionally, Zaller et al. (2008) detected a significant effect of a short distance to the overwintering habitats of *C. pallidactylus* and its abundance, while no effect was discovered for the high proportion of acreage of WOSR to weevil abundance (Moser et al. 2009). Anyhow, it can be concluded that landscape effects can overlap the output of the forecast system presented here. Therefore, these factors have to be taken into account in the future development of decision support tools for an integrated pest management system. Risk maps indicating threats for the next cropping season to select locations with a minor

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pressure of insect pests must be developed. These risk maps could also be easily integrated into digital farm management systems to optimise the necessary operational procedures in plant protection.

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REFERENCES

Bale J.S., Masters G.J., Hodkinson I.D., Awmack C., Bezemer T.M., Brown V.K., Butterfield J., Buse A., Coulson J.C., Farrar J., Good J.E.G., Harrington R., Hartley S., Jones T.H., Lindroth R.L., Press M.C., Symrnioudis I., Watt A.D., Whittaker J. (2002): Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology, 8: 1–16.

Beyer M., El Jarroudi M., Junk J., Pogoda F., Dubos T., Görgen K., Hoffmann L. (2012): Spring air temperature accounts for the bimodal temporal distribution of *Septoria tritici* epidemics in the winter wheat stands of Luxembourg. Crop Protection, 42: 250–255.

Damos P. (2015): Modular structure of web-based decision support systems for integrated pest management. A review. Agronomy for Sustainable Development, 35: 1347–1372.

Eickermann M., Ulber B. (2010): Screening of oilseed rape and other brassicaceous genotypes for susceptibility to *Ceutorhynchus pallidactylus* (Mrsh.). Journal of Applied Entomology, 134: 542–550.

Eickermann M., Junk J., Görgen K., Hoffmann L., Beyer M. (2013): Ensemble-based analysis of regional climate change effects on the pod midge (*Dasineura brassicae* Winn.) in oilseed rape. IOBC-WPRS Bulletin, 96: 23–28.

Eickermann M., Ulber B., Hoffmann L., Junk J. (2014a): Improving phenological forecasting models for rape stem weevil, *Ceutorhynchus napi* Gyll., based on long-term multi-site datasets. Journal of Applied Entomology, 138: 754–762.

Eickermann M., Beyer M., Goergen K., Hoffmann L., Junk J. (2014b): Shifted migration of the rape stem weevil (*Ceutorhynchusnapi*) linked to climate change. European Journal of Entomology, 111: 243–250.

Eickermann M., Junk J., Hoffmann L., Beyer M. (2015): Forecasting the breaching of the control threshold for *Ceutorhynchus pallidactylus* in oilseed rape. Agricultural ad Forest Entomology, 17: 71–76.

Ferguson A.W., Skellern M.P., Andreas J., von Richthofen J.-S., Watts N.P., Bardsley E., Murray D.A., Cook S.M. (2015): The potential of decision support systems to improve risk assessment for pollen beetle management in winter oilseed rape. Pest Management Science, 72: 609–617.

Hahn D.A., Denlinger D.L. (2011): Energetics of insect diapause. Annual Review of Entomology, 56: 103–121.

Hervé M. (2017): Breeding for insect resistance in oilseed rape: Challenges, current knowledge and perspectives. Plant Breeding, 137: 27–34.

Juhel A.S., Barbu C.M., Franck P., Roger-Estrade J., Butier A., Bazot M., Valantin-Morison M. (2017): Characterization of the pollen beetle, *Brassicogethes aeneus*, dispersal from woodlands to winter oilseed rape fields. PLoS ONE 12(8). doi: 10.1371/journal.pone.0183878

Junk J., Eickermann M., Görgen K., Beyer M., Hoffmann L. (2012): Ensemble-based analysis of regional climate change effects on the cabbage stem weevil (*Ceutorhynchus pallidactylus* (Mrsh.)) in winter oilseed rape (*Brassica napus* L.). The Journal of Agricultural Science, 150: 191–202.

Junk J., Jonas M., Eickermann M. (2016): Assessing meteorological key factors influencing crop invasion by pollen beetle (*Meligethes aeneus* F.) – past observations and future perspectives. Meteorologische Zeitschrift, 25: 357–364.

Juran I., Gotling Čuljak T., Grubišić D. (2011): Rape Stem Weevil (*Ceutorhynchus napi* Gyll. 1837) and Cabbage Stem Weevil (*Ceutorhynchus pallidactylus* Marsh. 1802) (Coleoptera: Curculionidae) – important oilseed rape pests. Agriulturae Conspectus Scientificus, 76: 93–100.

Klueken A.M., Hau B., Ulber B., Poehling H.-M. (2009): Forecasting migration of cereal aphids (Hemiptera: Aphididae) in autumn and spring. Journal of Applied Entomology, 133: 328–344.

Klem K., Spitzer T. (2017): Prediction model for cabbage stem weevil *Ceutorhynchus pallidactylus* Mrsh. occurrence on winter rape based on an artificial neural network Agricultural and Forest Entomology, 19: 302–308.

Lefebvre M., Langrell S.R.H., Gomez-y-Paloma S. (2015): Incentives and policies for integrated pest management in Europe: a review. Agronomy for Sustainable Development, 35: 27–45.

Moser D., Drapela T., Zaller J.G., Frank T. (2009): Interacting effects of wind direction and resource distribution on insect pest densities. Basic and Applied Ecology, 10: 208–215.

Rusch A., Valantin-Morison M., Roger-Estrade J., Sarthou J.-P. (2012): Local and landscape determinants of pollen beetle abundance in overwintering habitats. Agricultural and Forest Entomology, 14: 37–47.

Rusch A., Valantin-Morison M., Sarthou J.P., Roger-Estrade J. (2013): Effect of crop management and landscape context on insect pest populations and crop damage. Agriculture, Ecosystems and Environment, 166: 118–125.

Schütte F. (1970): Nutzung von Schwellenwerten für langfristige Prognosen. Journal of Plant Disease and Plant Protection, 77: 648–655.

Spitzer T., Matušinský P., Spitzerová D., Bílovský J., Kazda J.: (2014). Effect of flight activity of stem weevils (*Ceuto-*

https://doi.org/10.17221/93/2019-PPS

rhynchus napi, *C. pallidactylus*) and application time on insecticide efficacy and yield of winter oilseed rape. Plant Protection Science, 50: 129–134.

Venäläinen A., Heikinheimo M. (2002): Meteorological data for agricultural applications. Physics and Chemistry of the Earth, Parts A/B/C, 27: 1045–1050.

Williams I.H. (2010): The Major Insect Pests of Oilseed Rape in Europe and Their Management: An Overview. In: Williams I.H. (ed.): Biocontrol-Based Integrated Management of Oilseed Rape Pests. Dordrecht, Springer.

Witten I.H., Frank E., Hall M.A. (2011): Data Mining: Practical Machine Learning Tools and Techniques. 3rd Ed., Burlington, Morgan Kaufmann.

Zaller J.G., Moser D., Drapela T., Schmöger C., Frank T. (2008): Insect pests in winter oilseed rape affected by field and landscape characteristics. Basic and Applied Ecology, 9: 682–690.

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