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Western corn rootworm adult captures as a tool for the larval damage prediction in continuous maize

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Abstract

Continuous maize production in Croatia and Central Europe is at serious risk from western corn rootworm (WCR) (*Diabrotica virgifera virgifera,* LeConte) activity. When alternatives to sowing continuous are not feasible, farmers will need a reliable tool that will allow them to choose fields for continuous cultivation. The decision could be based on assessing the adult populations in fields from the previous year. Non-baited yellow sticky traps [Pherocon AM (PhAM)] could be utilized as a practical tool for sampling. The main objective of this study was to determine which WCR adult population data collected by PhAM traps could most reliably predict the subsequent WCR larval population and damage. Adult WCR population densities in 30 cornfields were determined weekly over a 74 day period each year (24th to 35th week) from 2006 to 2009. In addition to root damage and plant lodging measurements, soil and root sampling were conducted to measure the WCR larval population in continuous maize fields. Larval infestation is best predicted by maximal weekly capture (MWC) but, root damage is better predicted by capture of adults in the 31st week of previous year. For the prediction of plant lodging, MWC, average daily capture (ADC) and the capture of adults in 29th week were found to be equivalent. To save money and to shorten the sampling period, farmers should employ PhAM traps between the 29th and 32nd week. The estimated WCR adult capture that could cause significant larval infestation is ≥ 22 adults/trap in the 29th week. Significant future root damage is predicted if ≥ 41 adults/trap are captured in the 31st week. Plant lodging is predicted if ≥ 36 adults/trap (for 90% of upright plants) or ≥ 32 adults/trap (for 10% of partially lodged plants) are captured in 29th week. Findings will help to develop economic threshold models and improved decision-making for WCR management.

Introduction

Maize is the most important arable crop in Croatia. It is produced on approximately 300 000 ha per year and has an average yield of approximately 8 t/ha (Statistical annual 2009). Maize is cultivated more frequently in western Croatia than in eastern Croatia, because farmers' use it to feed cattle. In eastern Croatia, maize is primarily grown for grain. Western corn rootworm (WCR) (*Diabrotica virgifera virgifera,* LeConte, 1868) is the most important USA maize pest (Metcalf 1986 cit. Gerber et al. 2005). The extremely invasive behaviour of WCR increases its importance in Central Europe (an important maize growing area). In Europe, WCR was initially detected in Serbia in 1992 (Bača 1994). Szalai et al. (2011) estimated that the introduction occurred between 1979 and 1984. Multiple independent European introductions have occurred (Ciosi et al. 2008). Western corn rootworm has now spread to 20 European countries. Central European countries and Italy host the highest populations of WCR and regularly suffer damage from the pest.

Maceljski and Igrc Barčić (1993) and Igrc Barčić and Maceljski (1997, 1998) suggested that WCR could become an important maize pest in Croatia. An average yearly spread of approximately 40 km was confirmed by Igrc Barčić et al. (2003a). The possibility of acclimatization was investigated by Maceljski and Igrc Barčić (1994) and confirmed by Dobrinčić (2001). Dobrinčić (2001) estimated that WCR populations in Croatia increased annually by 1.7-fold at the lowest rate and 3.6-fold at the highest rate during the period from 1995 to 2000. Szalai et al. (2011) estimated that the WCR population growth in Hungary, and Croatia is 4-fold. Igrc Barčić et al. (2003b) documented the first serious damage from WCR larvae in Croatia. Visible damage (lodging and significant yield loss) is a regular occurrence, especially in areas where a higher percentage of continuous maize is sown.

Guidelines for the integrated production of maize suggest the avoidance of continuous maize sowing (Ministry of Agriculture 2011). However, very often, there is economic need to plant maize each season, particularly for dairy farmers. In such circumstances, farmers will need a reliable tool that will allow them to choose the most suitable field for continuous sowing. Most of the studies related to damage forecasting (Branson et al. 1980, 1982, 1983; Foster et al. 1986; Gray and Tollefson 1987; Spike and Tollefson 1989; Riedell and Schumacher 1994; Kuhar et al. 1997) and risk assessment for WCR were conducted in the USA. Western corn rootworm risk assessment investigations are absent for European and Croatian agro-ecological conditions. The guidelines for integrated maize production in Croatia (Ministry of Agriculture 2011) do not include a threshold level for WCR abundance.

To predict possible WCR larval damage in continuous maize and to make decisions regarding the appropriate preventive management (i.e. crop rotation or application of insecticides), farmers need monitoring tools. It is commonly accepted that a decision about preventive management should be based on the adult population in the same field during the previous year (Musick et al. 1980; Foster et al. 1982; Tollefson 1990; Roselle 1977 cit. Darnell et al. 1999). In the USA, Pherocon AM (PhAM) trapping and visual counts are two commonly used methods for identifying maize fields that contain a sufficient number of adult WCR to cause economic root damage by larvae the following year. In addition to knowing the economic threshold (ET) for each method, it is also important to determine an interval for sampling that will yield demonstrably predictive data to compare with the ET. Additionally, it is very important to know the possible impact of weather on the reliability of the prediction. For years, it has been suggested that whole-plant counts of WCR adults could be used as a practical sampling tool to determine the need for larval control in maize fields in the following year. Hein and Tollefson (1985) demonstrated that the PhAM was as effective as a practical tool for sampling rootworm because of its compactness, easy installation and use, commercial availability and low cost. Bažok et al. (2011) suggested that the commonly used methods of visual counting and PhAM sampling are also effective to estimate the population densities of WCR in the Central European region. Hein and Tollefson (1985) suggested that the PhAM traps should be installed during the last 3 weeks of August. They recommended the capture of 40 adults/PhAM/week or an average capture of six adults/PhAM/day as the ET. They found that the ET could vary among years of investigation (Wilde 1999 cit. Bažok et al. 2011). In general, the ETs used by Midwestern USA farmers are one beetle/plant for whole-plant counts or the capture of 40 beetles/PhAM/week. ET data for European conditions are not yet widely published. Some investigations (Bažok et al. 2008; Bažok et al. 2011) indicated that the ET may vary depending on weather conditions, but is between 30 and 40 beetles/PhAM/week; however, there is a lack of data for most of Europe. The time period in which PhAM trap captures should be observed to predict larval damage with the highest accuracy remains unknown for European maize cultivation.

The main objective of our study was to determine which data on the WCR adult population collected by the PhAM traps (the maximal weekly capture (MWC) of WCR adults and the average daily capture of WCR adults) could reliably predict the WCR larval population and damage (expressed as root damage and as plant lodging). We also aimed to determine the time period in which the adult capture data should be collected to provide the highest correlation with damage to maize in the following year.

Materials and Methods

The investigation was conducted in the maize fields within three maize cultivation regions of Croatia. Each region was represented by one or two localities (villages). The region of the city of Vukovar was represented by two localities (Bošnjaci and Tovarnik), the region of the city of Virovitica was represented by two localities (Terezino Polje and Orahovica), and the region of the city of Koprivnica was represented by one locality (Ferdinandovac). The investigation was conducted during four field seasons that were divided into three cycles. One cycle spanned 2 years. In the first year, the adult population was measured. In the second year, the same fields were sown with maize, and the WCR larval population density and root damage were measured. The investigation cycles were as follows: 2006/2007, 2007/2008 and 2008/2009. In the first year of investigation (2006), five maize fields were monitored for the WCR adult population in each region (i.e. 15 fields). The same fields were monitored the next year (2007), and the WCR larval density, root damage and plant lodging were assessed. Additionally, five-first-year maize fields were monitored for the WCR adult population in each region (i.e. additional 15 fields) in the same year (2007). Finally, in 2007, 30 fields (distributed in three regions) were monitored for their WCR adult population. Of these fields, the 15 (i.e. five in each region) with the highest WCR adult populations were selected and assessed in 2008 for their WCR larval density and root damage. The same procedure was repeated in the 2008/2009 cycle. Fifteen data sets were to be collected in each cycle. The fields were cultivated using conventional methods and sown with hybrids from the FAO group 400 and 500. The use of any type of insecticides was avoided. Depending on weed abundance and field history, weeds were controlled with pre- and post-emergence herbicides.

The adult population density was established by placing three Pherocon Adult Monitoring® traps (hereafter PhAM; Trécé Inc., Salinas, CA 93912) in the central row of the field at the height of the maize ears in the 23rd week of the year. The first trap was set up 20 m from the field edge. The other two traps were placed at 30 m intervals. Data on the WCR population density used for the statistical analysis were collected from the 24th to the 35th week of the year. The beginning of the monitoring period corresponded to Julian dates (JD) 169 or 170 and the end of the monitoring corresponded to JD 244 or 245. The week with the highest adult capture was chosen for each field. The mean number of adults captured per trap in this particular week was used as the maximal weekly capture of adults. The average daily capture of adults (ADC) was calculated by dividing the mean total captures by the number of days that the traps were exposed in the field (74 days). The mean total capture of the WCR adults in each particular week of monitoring was analysed separately. The 29th and the 31st week were chosen for further data processing because in these weeks the highest correlation was observed. The WCR larval population density was established in the 23rd (2008) or the 24th (2007, 2009) week of the year, which corresponded to JD 170 (in 2007), 163 (in 2008) and 167 (in 2009). Because different maize hybrids were planted in each year, the maize phenology stage when larval densities were established differed from field to field and from year to year. Maize phenology stage varied from R18 to R34 according to the phenological growth stages and the BBCH identification keys of the maize (Stauss 1994). The degree-day accumulation was calculated based on the soil temperature at the depth of 10 cm. We used two thermal thresholds: 11.0°C as it was proposed by Bergman and Turpin (1986) and 11.2°C proposed by Levine et al. (1992). The accumulated heat units on the day when the WCR larval population densities were measured differed between the year and locality. According to Bergman and Turpin (1986), the accumulated heat units for the days when larval sampling was conducted ranged between 528.2 and 584.7°C in 2007, 432.0 and 462.3°C in 2008, and 460.2 and 582.4°C in 2009. According to the Levine et al. (1992) threshold, the accumulated heat units ranged between 512.2 and 569.7°C in 2007, 419.5 and 449.3°C in 2008, and 445.2 and 567.2°C in 2009. Ten plants in each of four randomly selected rows in the field were dug (i.e. 40 plants per field) to assess the larval population density. Four sets of 10 plants were collected from each field for a total of 40 plants/field for root damage evaluation. Scores on the Node Injury Scale (NIS, 0–3) were recorded at each of the fields in the 29th week during each year of investigation, which corresponded to JD 203 (in 2007 and in 2009) and 206 (in 2008). At that time, the maize phenology stages varied from R65 to R67 according to the BBCH scale (Stauss 1994).

Plant lodging was estimated in the 38th week of the year in all years (corresponding to JD 261, 267 and 265). At that time, the maize phenology stages varied from R83 to R97 according to BBCH scale (Stauss 1994). Lodging was measured using 100 plants in five randomly selected rows in each field (i.e. 500 plants per field). The plants were classified as follows: upright, partially and fully lodged. The partially lodged plants were those plants whose stalk closed at an angle <45° from an upright plant. The fully lodged plants were those whose stalk closed at an angle more than >45° from an upright plant.

Weather measurements which included the average air temperature and rainfall, and the maximum and minimum daily air temperatures for each year were recorded from the respective county meteorological stations. There was a distance of up to 30 km between the field localities and the meteorological stations.

Factors that prevented data collection from all of the planned fields included: low number of WCR adults, flooding, other extreme weather conditions, and early maize harvesting. As a result, in some years the number of data sets was lower.

Equation 1 depicts the main model for the linear regression analysis between the independent and dependent variables.

$$y = x + \text{cycle} + x : \text{cycle} \tag{1}$$

y = dependent variable (average number of larvae per root, average node injury score (NIS 0–3), average per cent of plant lodging);

x = independent variable (average MWC, ADC, average weekly captures from the 24th to the 35th week of the year).

All of these data were analysed by ANOVA to determine whether there was a significant effect of the cycle (e.g. weather conditions) on the model. If no significant interaction with the cycle was present, data were pooled across cycles for analysis and represented with one line. In contrast, if significant interaction with the cycle was present, data were presented with three separate lines. The cycle resulting with the steepest slope was chosen for establishing ET. The regression analysis was performed using a SAS ver. 9.1.2. (SAS Institute 2004).

Results

The linear regression analyses between adult WCR captures and average number of larvae per root, regression equations and estimated WCR adult capture that predict the WCR larval population density of 0.5 larvae per root in continuous maize are shown in table 1.

The amount of variability was measured using coefficient of determination (R^2). The coefficient of determination indicated that the number of larvae per root was most accurately predicted by the MWC of adults (R^2 = 0.521). There was a significant interaction between cycle and MWC (P = 0.024). The line derived from the 2006/2007 cycle resulted in the steepest slope indicating that only weather conditions worse (i.e. warmer and drier) than those in that cycle can provide a lower ET. Therefore, the line representing cycle 2006/2007 was chosen as the basis for the prediction equation. An average infestation of 0.5 larvae per root could be expected if a MWC of ≥ 66 adults/trap was observed in the previous year. The number of larvae per root was less well predicted by ADC (R^2 = 0.298). The capture of adults in the 29th week was less reliable than the MWC and more reliable than the ADC (R^2 = 0.397). A significant interaction was also established between cycle, and ADC and capture of adults in the 29th week (P = 0.046 and P = 0.0061, respectively).

The data on linear regression analysis between WCR adult captures and average node injury score (NIS 0–3), regression equations and estimated WCR adult capture that predict the node injury score of

Table 1 The linear regression analysis between adult western corn rootworm (WCR) captures (expressed as maximum weekly capture on Pherocon AM trap (MWC), average daily capture of adults on Pherocon AM traps (ADC) and as captures of adults in the 29th week of the year) and average number of larvae per root, regression equations and estimated WCR adult captures that predict the WCR larval population density of 0.5 larvae per root in continuous maize

Independent variable	Estimated WCR adult capture	Coefficient of determination R^2	P[1]	n (model)	Regression equation	Based on the data of the cycle	n (regression equation)
MWC	66	0.521	<0.0001**	39	$y = 0.0173\,x - 0.6418$	06/07	14
MWC: CYC[2]			0.0240*				
ADC	2.33	0.298	0.0009**	39	$y = 0.2224\,x - 0.0181$	06/07	13
ADC: CYC[3]			0.0460*				
29th	22	0.397	0.0041**	37	$y = 0.024\,x - 0.0270$	06/07	13
29th: CYC[4]			0.0061**				

[1]Based on ANOVA indicated n.s. not significant at P > 0.05; significant* at 0.05 > P > 0.01; and highly significant** at P < 0.01.
[2]MWC: CYC – interaction between maximal weekly captures of adults on PhAM and cycle of investigation.
[3]ADC: CYC – interaction between average daily captures of adults on PhAM and cycle of investigation.
[4]29th: CYC – interaction between captures of adults on PhAM in 29th week of the year and cycle of investigation.

0.75 (NS 0–3) in continuous maize are shown in table 2.

The amount of variability (R^2) indicates that the average node injury score was best predicted by the capture of adults in the 31st week ($R^2 = 0.636$). As there was no significant interaction with cycle, data were pooled across cycles for analysis. An average node injury score of 0.75 could be expected if we observed the capture of ≥ 41 adults/trap in the 31st week. The average node injury score was less accurately predicted by the MWC and ADC ($R^2 = 0.298$ and $R^2 = 0.261$, respectively). A significant interaction between cycle and MWC and ADC (P = 0.029 and P = 0.046, respectively) was established.

The data on linear regression analysis between WCR adult captures and plant lodging, regression equations for plant lodging (y) on WCR adult capture (x) and estimated WCR adult capture that predict 90% of upright plants or 10% of plant lodging in continuous maize are shown in table 3. The amount of variability (R^2) indicates that the percentage of upright plants and the percentage of partially lodged plants could be predicted by the MWC, ADC or the capture of adults in the 29th week. Significant coefficients of determination (R^2) varied between 0.200 and 0.368. As there was no significant interaction with cycle, data were pooled across cycles for analysis. If a MWC of ≥ 36 adults/trap/week, and an ADC up to 3.18 adults/trap, or if the capture up to ≥ 36 adults in the 29th week of the year were observed, then upright plants could be expected at a rate of 90%. Fewer plants will be upright if the captures are higher. If the MWC is ≥ 62 adults/trap/week, the ADC is 4.01 adults/trap, or the capture observed in the 29th week of the year is 32 adults/trap, partially lodged plants could be expected at a rate of 10%.

Discussion

The highest significant regression coefficients for all three independent variables and the WCR larval density were observed in the 2006/2007 cycle (table 1). In that cycle, the increases in WCR adult captures had the greatest influence on increases in the average number of larvae in continuous maize. One of the reasons why the coefficients of determination are moderate could be that, in 2008 and 2009, the larval populations were low; this was later verified by a lower level of root damage compared to 2007. The low larval population could be the result of the poor conditions for oviposition in the previous year, larval mortality and larval development in the spring. It is possible that the timing of larval sampling did not correspond with the peak population or the period when the larvae were the most visible in the field. Larval sampling was conducted on JD 170, 163 and 167 in 2007, 2008 and 2009, respectively. At the time of larval sampling in 2007 accumulated heat units were the highest. According to Bergman and Turpin (1986), over 50% of males must have already emerged and a significant part of the larval population had already finished their development. The rest of the larval population was in the third larval instar', or they were present as pupae. The sampling date in 2007 was coincident with the appearance of the third larval instar. The earliest larval sampling was conducted in 2008 when accumulated heat units on the sampling date were the lowest. At the time of

Table 2 The linear regression analysis between western corn rootworm (WCR) adult captures (expressed as maximum weekly capture on Pherocon AM trap (MWC), average daily capture of adults on Pherocon AM traps (ADC) and as captures of adults in the 31st week of the year) and average node injury score (NIS 0–3), regression equations and estimated WCR adult captures that predict the node injury score of 0.75 (NIS 0–3) in continuous maize

Independent variable	Estimated WCR adult capture	Coefficient of determination R^2	P[1]	n (model)	Regression equation	Based on the data of the cycle	n (regression equation)
MWC	69	0.298	0.0205*	38	$y = 0.0105\,x + 0.0267$	06/07	15
MWC: CYC[2]			0.0290*				
ADC	3.66	0.269	0.0009**	38	$y = 0.1086\,x + 0.3520$	06/07	15
ADC: CYC[3]			0.0460*				
31st	41	0.636	0.0439*	39	$y = 0.0131\,x + 0.2175$	06–09	39
31st: CYC[4]			0.8669 n.s.				

[1]Based on ANOVA indicated n.s. not significant at P > 0.05; significant* at 0.05 > P > 0.01; and highly significant** at P < 0.01.

[2]MWC: CYC – interaction between maximal weekly captures of adults on PhAM and cycle of investigation.

[3]ADC: CYC – interaction between average daily captures of adults on PhAM and cycle of investigation.

[4]31st: CYC – interaction between captures of adults on PhAM in 31st week of the year and cycle of investigation.

Table 3 The linear regression analysis between western corn rootworm (WCR) adult captures (expressed as maximum weekly capture on Pherocon AM trap (MWC), average daily capture of adults on Pherocon AM traps (ADC) and as captures of adults in the 29th week of the year) and plant lodging, regression equations for plant lodging (*y*) on WCR adult capture (*x*) and estimated WCR adult captures that predict 90% upright plants or 10% plant lodging in continuous maize

Dependent variable	Independent variable	Estimated WCR adult capture	Coefficient of determination (R^2)	P[1]	n[2] (model/ regression equation)	Regression equation	Based on the data of the cycle
Upright plants	MWC	36	0.293	0.0046**	39	$y = 0.1699\,x + 96.132$	06–09
	MWC: CYC[3]			0.269 n.s.			
	ADC	3.18	0.331	0.0083**	38	$y = -3.177\,x + 100.10$	06–09
	ADC: CYC[4]			0.165 n.s.			
	29th	36	0.334	0.0062**	39	$y = -0.2169\,x + 97.77$	06–09
	29th: CYC[5]			0.052 n.s.			
Partially lodged plants	MWC	62	0.323	0.0061**	39	$y = 0.1464\,x + 0.9230$	06–09
	MWC: CYC			0.257 n.s.			
	ADC	4.01	0.368	0.0090**	39	$y = 2.5229\,x + 0.7070$	06–09
	ADC: CYC			0.147 n.s.			
	29th	32	0.200	0.0004**	39	$y = 0.2000\,x + 3.5930$	06–09
	29th: CYC			0.060 n.s.			
Fully lodged plants	MWC			0.547 n.s.			
	MWC: CYC			0.073 n.s.			
	ADC			0.575 n.s.			
	ADC: CYC			0.060 n.s.			

[1]Based on ANOVA, indicated n.s. not significant at P > 0.05; significant* at 0.05 > P > 0.01; and highly significant** at P < 0.01.
[2]n (model) data number = n (regression equation) data number.
[3]MWC: CYC – interaction between maximal weekly captures of adults on PhAM and cycle of investigation.
[4]ADC: CYC – interaction between average daily captures of adults on PhAM and cycle of investigation.
[5]29th: CYC – interaction between captures of adults on PhAM in 29th week of the year and cycle of investigation.

the 2008 larval sampling 50% or fewer of the larvae must have emerged (Levine et al. 1992). At the time of larval sampling in 2009, accumulated heat units ranged between those accumulated in 2007 and in 2008. Our results suggest that if sampling is conducted too early in the season, many larvae will be so small that they may not be detected. This detection problem could influence the larval density estimation. It is important to conduct the larval sampling at the time when the third larval instar is present because this instar is the most visible. Under Croatian conditions, the third larval instar is present for up to 29 days (Dobrinčić 2001). Years of investigation have established the differences in the larval populations. The highest larval population was measured in 2007. Favourable weather condition and high adult population in August 2006 together with favourable weather conditions in spring 2007 may have contributed to successful larval development and a high larval population in 2007. A high adult population was measured in 2006. The ADC from the majority of the fields was three or more beetles/trap/day. The WCR adults lived until September and the oviposition period lasted longer because of a lack of extreme temperatures and because of favourable distribution of adequate precipitation. As indicated by Agosti et al. (2006), high levels of humidity stimulated oviposition in females. According to Toepfer and Kuhlmann (2006), the average mortality of the first larval instar is 48.6%. A portion of larval mortality could be caused by low temperatures (Chiang 1973) and by the lack of moisture (MacDonald and Ellis 1990). In the spring of 2007, we did not observe climatic conditions that could account for high mortality of the eggs and first larval instars. Over the entire investigation, June 2007 was the warmest month. It is likely that this warmth had a positive influence on the rate of larval development as it was observed by other workers (Kuhlman et al. 1970; Bergman and Turpin 1986; Jackson and Elliott 1988; Davis et al. 1996).

Depending on which independent variable was used, results of the regression analyses differed among the investigated cycles indicating that the cycle strongly influenced the relationship between variables. Thus, the regression coefficients are the highest for 2006/2007 cycle. In addition to the MWC and ADC, the capture of the adults in the 29th week of the year indicated very high accuracy in predicting the larval population in continuous maize.

When compared with the coefficients of determination for the average number of larvae per plant, the coefficients of determination for the node injury scores (table 2) are lower (except for the 31st week). According to these results, it could be concluded that the MWC and the ADC of adults on PhAM are the better tools for prediction of larval population than for prediction of node injury scores (tables 1 and 2). The lower accuracy of the prediction of node injury scores vs. larval population might be explained by the longer-time span between the adult capture and the node injury score assessment. As evidenced by the results of Hein and Tollefson (1985), Foster et al. (1986) and Kuhar and Youngman (1998), environmental factors might influence the correlation between adult capture and the node injury scores assessment during this period. The time span between the adult capture and larval population assessment is shorter and less environmental influences could be expected to accumulate.

We observed few similarities with the results of Kuhar and Youngman (1998) and Hein and Tollefson (1985) who investigated the relationship between the adult captures and node injury scores in the USA. The discrepancies between our results and results of Foster et al. (1986) and Tollefson (1990) might be explained by differences in the adult population estimation methods that were used.

The cycle of investigation influenced the regression equation for the MWC, ADC and root damage. As a result of the highest larval population, the highest root damages were established during the 2006/2007 cycle. Thus, the regression coefficients are the highest for this cycle. The capture of adults in the 31st week of the year indicated strong relationship with the prediction of the node injury score. This relationship was not influenced by the cycle of investigation.

According to the coefficients of determination, the MWC, ADC and the capture of beetles in the 29th week of the year are similar as predictors of the percentage of partially lodged and upright plants (table 3). There is no literature to support the discussion concerning the relationship between adult captures and plant lodging. According to B. Varga (Personal Communication), serious water stress in the seed bed, as occurred in extremely dry conditions in 2007, could cause weak root development or damage serious enough to lower the larval population. This observation is supported by the statement of Spike and Tollefson (1989) that the relationship between the root size and plant lodging is significant. During our investigation, the rainfall differed greatly between the years. The lowest (25.0 mm) and highest (85.8 mm) total rainfall for May was measured in Virovitica in 2008 and 2007, respectively. For June, the lowest (35.1 mm) and highest (188.0 mm) rainfall amounts were also measured at Virovitica for 2007 and 2008, respectively. However, this variation did not influence the interaction of the MWC and the ADC of adults on PhAM and the cycle.

Sutter et al. (1990) and Spike and Tollefson (1989) indicated that as lodging increases the yield loss also increases in continuous maize. Thus, the prediction of plant lodging is more important as a forecast indicator of damage. It was not possible to use our data to predict the percentage of fully lodged plants. However, we observed that the number of fields with a significant percentage of fully lodged plants was higher if the plants had developed in dry weather conditions. Both, drought and strong winds increase the percentage of fully lodged plants when the maize ears become heavy (C.R. Edwards, Personal Communication).

To predict WCR damage in continuous maize we used ETs of 0.5 larvae per root (table 1), a root injury rating of 0.75 (according to NIS 0–3) (table 2) and 10% of partially lodged or 90% of upright plants (table 3). Based on maize cultivation conditions in Croatia and our experiences, we concluded that 0.5 larvae per root and 10% of partially lodged or 90% of upright plants may result in economic losses. Authors from USA (Hein and Tollefson 1985; Sutter et al. 1990; Oleson et al. 2005) reported that root injury rating of 0.75 (according to NIS 0–3) would result in economic losses. Based on the established regression equations, we predicted the number of adults on PhAM traps, which would result with ET of 0.5 larvae/plant or with root injury rating of 0.75. For three of four variables, the thresholds based on the MWC in our investigations are over 60 beetles/PhAM trap/week and are much higher than the threshold commonly accepted in the USA, which is 40 beetles/PhAM trap/week (Hein and Tollefson 1985). This difference is understandable because Hein and Tollefson's (1985) investigation was based on a period of 38 days of sampling during August, whereas in our investigations, the sampling lasted 74 days from the end of June until the end of August. The Hein and Tollefson's (1985) investigation was related to two rootworm species, which could also influence the differences between our results. Also, they used the mean number of beetles per trap, while we used the maximum number. This variation in methodology might be an additional reason why we obtained different results. The MWC in our investigations were usually observed in July. It is well documented that the capture of males is most prevalent in June and the beginning of July; however, the capture of females on PhAM is most prevalent in August (Kuhar and Youngman 1995; Darnell et al. 2000). Thus, our established thresholds are based on the similar capture of both sexes in the ear zone. In contrast, Hein and Tollefson (1985) based their threshold on 38 days of capture of females at a lower level on the plant.

Our analyses suggested that a MWC of ≥ 66, ADC of 2.33 and ≥ 22 adults captured on PhAM in the 29th week of the year would produce an average infestation of 0.5 larvae/root. Additionally, a MWC of ≥ 69 adults/trap/week, ADC of 3.66 adults and capture of ≥ 41 adults/trap in the 31st week would produce an average node injury score of 0.75 (NIS, 0–3). These thresholds are somewhat higher than the results of Kuhar and Youngman (1998), who estimated that the capture of 23.7 adults on Olson yellow sticky traps would result in average root ratings (ISU, 1–6) of 3.5. Again, the difference in results might be explained by the different trap and the shorter period of time used.

The results indicate that at a MWC of ≥ 36, an ADC of 3.18 and ≥ 36 adults captured on PhAM in the 29th week of the year, a 90% rate of upright plants could be expected. These results also indicate that at a MWC of ≥ 62, an ADC of 4.01 and ≥ 32 adults captured on PhAM in the 29th week of the year, a 10% rate of partially lodged plants could be expected.

After conducting the regression analyses for each particular week, we concluded that the capture of adults in the 29th week of the year could be used as a valuable predictor of the larval population. Additionally, the capture of adults in the 31st week of the year was the best predictor of the root damage. Hein and Tollefson (1985) suggested that using adult capture in the 34th week of the year could be used to best predict root damage. However, their results are based on counting only females. Foster et al. (1986) suggested that using adult captures in the 32nd week of the year was the best predictor of root damage. If the adult population is observed by Olson yellow sticky traps, then Kuhar and Youngman (1998) suggested that the 33rd week of the year was the best period for prediction. Another reason for the difference in results might be that the phenology and population dynamics of WCR differ between the regions of the USA and Croatia because the climatic data might be different. Maceljski and Igrc Barčić (1994) compared 10 years climatic data between maize growing area in USA (Columbia, Missouri and Beltsville, Maryland) and Croatia (Zagreb and Osijek). Their comparisons showed differences in average winter air temperatures Columbia (13.2°C) and Beltsville (13.9°C) vs. Zagreb (10.6°C) and Osijek (11.3°C). Also, differences were observed in average amount of yearly rainfall in Columbia (1061 mm) and Beltsville (1338 mm) vs. Zagreb (871 mm) and Osijek (686 mm). However, their data were not statistically analysed and we could not be sure whether the differences were significant. The 31st week of the year corresponds with the end of July and the beginning of August. Bažok et al. (2008) proposed the same period for conducting adult sampling because it provided the best correlation between the whole-plant and sticky trap counts.

Western corn rootworm adult capture can be used as a decision-making tool for prediction of the future larval population and damage in continuous maize. Because the weather significantly affects the year-to-year patterns, a strong relationship between the WCR adult capture and larval population or damage could not be established. The basis for establishing the MWC and ADC was the sampling period of 74 days, which is too long, and from the farmer's standpoint, is too time-consuming and expensive (especially if the traps are changed regularly). Given that adult monitoring from weeks 29 to 31 can predict injury under Croatian conditions with acceptable accuracy, a long monitoring period is unnecessary. Because weather conditions will vary from year to year, we propose that the most suitable time for monitoring the adult WCR abundance on PhAM sticky traps in maize is the last 2 weeks of July and the first 2 weeks of August.

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