Development of the Western corn rootworm, *Diabrotica virgifera virgifera* in soil

Vývin kukuričiara koreňového *Diabrotica virgifera virgifera* v pôde

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Abstract

Monitoring of developmental stages of the Western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) is an important aspect of its control. In the experiment there were analysed randomly selected plants of maize on six localities in western Slovakia, in the years 2008-2010 a 2014-2015. The aim of the study was to identify exact time of the emergence of the WCR adults in the consequence of different years and different localities and to find the best date for their eradication. The most of the WCR individuals at the northern locality were observed on 29 June and the first adults were found on 07 June, during colder year 2006. The development started about nine days earlier in the next year in southern Slovakia, because of extremely hot weather. The population of pest increased slower in 2008 than in previous years, and the highest appearance was monitored up-to 02 July. The first adults were monitored on 27 June in the years 2009-2010 as well as 2014-2015. Generally, the highest numbers of the first instar larvae were observed on 22 June at the locality Čiližská Radvaň. The second instar larvae and the most of adults was found on 20 June in Sokolce. On 29 June it was monitored the largest amount of the third instar larvae at the locality Čiližská Radvaň. The differences in the time of the emergence of adults depended on the year. Based on the monitoring in Slovakia, it can be expected the third instar larvae from second decade of June and the first adults in the last decade of June and in the first decade of July.

Keywords: adult, *Diabrotica virgifera virgifera,* locality, WCR, weather

Abstrakt

Monitorovanie vývinových štádií kukuričiara koreňového je dôležitým aspektom jeho regulácie. V experimente boli analyzované náhodne vybrané rastliny kukurice na

šiestich vybraných lokalitách Západného Slovenska, v rokoch 2008-2010 a 2014-2015. Cieľom tejto štúdie bolo určiť presný čas výskytu dospelých jedincov kukuričiara koreňového (*Diabrotica virgifera virgifera*) v dôsledku vplyvu ročníka a rôznych lokalít a nájsť najlepší dátum pre ich reguláciu. Počas chladnejšieho roku 2006 bolo v severnejšej lokalite najviac jedincov detekovaných 29. júna, a prvé imágo bolo pozorované 7. júla. O rok neskôr sa vývin na juhu Západného Slovenska vplyvom extrémne teplého počasia uskutočnil o 9 dní skôr. Nárast populácie škodcu bol v roku 2008 menší ako v predchádzajúcich rokoch, a maximálny počet imág bol zaznamenaný až 2. júla. Prvé imága v rokoch 2009-2010 a taktiež 2014-2015 boli pozorované 27. júna. Všeobecne, najvyšší počet lariev prvého instaru bol pozorovaný 22. júna v Čiližskej Radvani. Druhý instar lariev a najviac imág bolo sledovaných 20. júna v Sokolciach. Dňa 29. júna bolo monitorované najväčšie množstvo lariev tretieho instaru na lokalite Čiližská Radvaň. Rozdielnosť v čase výskytu imág ovplyvňoval ročník. Na základe monitoringu môžeme na Slovensku očakávať larvy tretieho instaru od druhej dekády júna, a prvé imága v poslednej dekáde júna a v prvej dekáde júla.

Kľúčové slová: *Diabrotica virgifera virgifera,* imágo, kukuričiar koreňový, lokalita, počasie

Introduction

The Western corn rootworm (*Diabrotica virgifera virgifera* LeConte; Coleoptera: Chrysomelidae) is economically important pest of maize, *Zea mays* L. (Krysan and Miller, 2012, Mahmoud et al., 2016). Over a billion dollars is lost annually to WCR from yield reductions and costs associated with management (Deitloff et al., 2016). The most widespread methods used to assess WCR abundance are whole-plant counts, visual inspection of both individual plants and yellow sticky traps or pheromone traps (Whitworth et al., 2002).

WCR is an invasive beetle species in Europe and native to North America (Lemic et al., 2016). The first discovery of WCR in Europe was in 1992 in the Surcin area near the Belgrade International Airport of Serbia (Yugoslavia) (Bača, 1994). The first detection of the WCR in Slovakia was reported in 2000 (Siviček, 2001), in the Czech Republic and in France it was in 2002 (Rasovsky and Vahala, 2002; Reynaud, 2002) and in Germany it was in 2007 (Vidal et al., 2005). The primary host for the larval development is maize (MacLeod et al., 2007). Eggs are the overwintering stage of the WCR and they are generally concentrated in the top 5-20 cm of soil, although they are situated deeper in dry soils (Schroeder et al., 2005). Eggs require a cold-induced diapause period before hatching, although a small proportion of the population may hatch during a warm period (Shaw and Hummel, 2003). In general, the first larvae of the WCR hatch from mid-May onwards in Central Europe. Larvae are present mainly from late May until late July (Komáromi et al., 2010). The third instar as the most damaging stage of WCR is expected to hatch between 16 June in Italy and 29 July in the Netherlands. The earliest emergence for the third instar was calculated for the south of Italy on 14 April and latest for the north of Germany on 28 August (European commission, 2004). The egg hatching begins in at least the first half of June and first adults appear at the end of June (Colombo et al., 2005). Under

the climatic conditions of Serbia larval hatching starts around 15 May (Sivčev et al., 2012). In Slovakia, hatching takes place from mid-May to the end of May, or at beginning of June (Cagáň et al., 2010). When the larvae hatch they burrow into the developing roots and the base of maize stems (Capinera, 2001). Rootworm larvae injure maize plants by feeding on root tissue, which can reduce a plant's rate of photosynthesis and which compromises water and nutrients supplied into the developing plants, change the nutrient content of the grain and may cause substantial reductions in grain yield (Tinsley et al., 2012). Environmental factors play a role in determining the severity of root injury (Tinsley et al., 2012).

The first and the second instar larvae tunnel from root tips upwards and can reach the plant base, leaving visible feeding scars. The third instar larvae generally feed on larger nodal roots near the plant stalk (Komáromi et al., 2010).

When root injury is severe, plants may become lodged (i.e. fail to stand up right) – root lodging may cause problems during harvest and can reduce yield by 11-34% (Estes et al., 2015; Pereira, 2015).

The highest number of larvae on root was observed around 20 June when feeding was the most intensive and plants become lodged as they lost roots (Sivčev et al., 2012). In the years with warmer springs, hatching and development start earlier, as for example in 2000 when maximum larval abundance was recorded as early as on 31 May (Sivčev and Tomašev, 2002).

Larvae pupate in soil chambers in the root zone. The pupal stage lasts for 7-10 days (Sivčev et al., 2012). Adults emerge in the summer and survive in maize fields until the autumn (Schaafsma et al., 1991). Western corn rootworm beetles usually begin to emerge from the soil in late June or by the end of June to early July (Komáromi et al., 2010). The adult emergence in the Netherland can start from early July until the end of August (Lammers, 2006). In Serbia, first adults emerge by the end of June. Their abundance increases during July, reaches maximum by the end of the month and continue to emerge until late October (Sivčev et al., 2012). The time of abundance peak of the WCR adults varies from year to year and region to region, but usually it was observed between mid-July and early August in Central and South-eastern Europe (Komáromi et al., 2010). The average life duration of adults is 5-6 weeks (Sivčev et al., 2012). Adult beetles cause damage by feeding principally on pollen, silk and young kernels (Vidal et al., 2005). After feeding the adults are able to lay eggs in the soil, generally in August – September (Lammers, 2006).

The aim of this study was to analyse the development of the WCR larvae on the maize roots and identify exact time of the emergence of the WCR adults in different years and at different localities. And, on the basis of such observations, to advise the farmers to find the best date for the eradication of the WCR adults.

Materials and methods

Field studies were conducted in western Slovakia at the localities of Rybany, Čiližská Radvaň, Sokolce and Veľké Chlievany during 2006 and 2007, and in Komoča during 2008-2010 and in Mojmírovce during 2014-2015.

Tables 1-7 show the dates of analyses. In each date there were analysed 40 randomly selected maize plants for the occurrence of the Western corn rootworm larvae, pupae and adults. For this purpose each plant was dig out and the soil around the roots was carefully checked for the pest. Climatic data were collected from Slovakian hydro-meteorologic institute (SHMU). Climatic data from the locality Komoča were collected by the agronomist of the farm Dipl. Ing. Ladislav Lukáč.

Results

Table 1 shows the number of the WCR larvae, pupae and adults in maize root cores at the locality Čiližská Radvaň during 2006. The averages of 31.00, 79.25 and 29.00 individuals in 40 maize root cores were found on 22 June, on 29 June and on 07 July 2006, respectively.

The largest number of larvae was recorded on 29 June 2006 at the locality Čiližská Radvaň (Table 1). The lowest number of larvae was observed at the locality Rybany on 07 July 2006 (Table 2). The first appearance of adults was recorded at the locality Čiližská Radvaň on 07 July 2006. At the coldest locality Rybany the adults were not found in the maize root cores on 14 July, whereas the first pupa was found on 07 July 2006 (Table 2). On the basis of the observations is well to see the development of larvae on maize roots over the time (Table 1. and 2.).

At the locality Čiližská Radvaň on 22 June 2006, 7.50 larvae were monitored in the stage of the first instar, 15.50 larvae in the stage of the second instar and 8 larvae in the stage of the third instar in 40 maize root cores. This ratio was changed on 29 June 2006 at Čiližská Radvaň. Together 1.75 larvae were ascertained in the first, 13.50 larvae in the second and 64.00 larvae in the third instar. On 22 June, the larvae of the second instar predominated, whereas larvae of the third instar predominated on 29 June. On the other hand almost only larvae of third instar were found on 07 July. In Table 1, it is possible to see the changes in the development of the larvae and the decrease of the number of younger instars larvae over the time. The same development of larvae over the time shows Table 2.

During 2006 the averages of 4.25, 2.00, 0.50 and 1.50 individuals in 40 maize root cores were recorded on 23 June, on 30 June, 07 July and on 14 July 2006 at Rybany, respectively. At the locality Rybany on 23 June, 0.50 larvae were monitored in the stage of the first, 2.50 larvae in the second and 1.25 larvae in the third instar in 40 maize root cores. This ratio was changed on 07 July 2006 in Rybany. Together no larvae were found both in the first and second instar and 0.25 larvae in the third instar. On 23 June, the larvae of the second instar predominated, whereas larvae of the third instar predominated on 14 July.

Table 1. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2006; Locality Čiližská Radvaň (Slovakia)

Tabuľka 1. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2006; Lokalita Čiližská Radvaň (Slovensko)

Stage	Čiližská Radvaň*					
	22 June		29 June		07 July	
	x	s	x	s	x	s
The first instar larvae	7.50	± 3.32	1.75	± 0.96	0.00	± 0.00
The second instar larvae	15.50	± 4.80	13.50	± 4.65	0.25	± 0.50
The third instar larvae	8.00	± 2.16	64.00	± 8.64	28.50	± 8.54
Sum of larvae	31.00	± 4.69	79.25	± 7.41	28.75	± 8.96
Pupae	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
Adults	0.00	± 0.00	0.00	± 0.00	0.25	± 0.50
Total	31.00	± 4.69	79.25	± 7.41	29.00	± 8.60

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Table 2. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2006; Locality Rybany (Slovakia)

Tabuľka 2. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2006; Lokalita Rybany (Slovensko)

Stage	Rybany*							
	23 June		30 June		07 July		14 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.50	± 1.00	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
The second instar larvae	2.50	± 0.58	0.75	± 0.96	0.00	± 0.00	0.00	± 0.00
The third instar larvae	1.25	± 1.26	1.25	± 0.96	0.25	± 0.50	1.50	± 1.00
Sum of larvae	4.25	± 1.50	2.00	± 1.82	0.25	± 0.50	1.50	± 1.00
Pupae	0.00	± 0.00	0.00	± 0.00	0.25	± 0.50	0.00	± 0.00
Adults	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
Total	4.25	± 1.50	2.00	± 1.83	0.50	± 1.00	1.50	± 1.00

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

The highest number of larvae was recorded in the maize root cores at the locality Sokolce on 20 June 2007 (Table 3). Less numbers of larvae were found at localities Čiližská Radvaň, Veľké Chlievany and Rybany in 2007, respectively. Numbers of the WCR larvae, pupae and adults in maize root cores in Sokolce and in Čiližská Radvaň are shown in Table 3.

Together 109.75 or 2.50 of the WCR individuals were monitored in 40 maize root cores on 20 June and on 04 July 2007 in Sokolce. There were found 14 pupae and 8 adults of the WCR on 20 June. At the same date, there were supervised 1.25 pupae and 2.00 adults of the WCR in Čiližská Radvaň (Table 3). In Veľké Chlievany, 4.00 and 1.25 pupae were observed, but none of adults were found in 40 maize root cores

on 27 June and on 07 July in 2007, respectively (Table 4). The first four pupae were found in Veľké Chlievany on 27 June, whereas it is about 17 days later than in Sokolce and Čiližská Radvaň. The adults were not observed on 27 June in Rybany, but 3.25 of pupae and 2.75 adults were recorded on 07 July in Rybany (Table 4). At the coldest locality Veľké Chlievany the adults were not monitored in maize root cores on 04 July 2007.

It was found that the first adults and pupae of the WCR were recorded at the localities Sokolce and Čiližská Radvaň (warm and dry climatic region) on 20 June in 2007 in Slovakia (Table 3). At the coldest observed locality (Rybany), the adults were not found in the maize cores until on 07 July (Table 4).

The first adult of the WCR was ascertained on 07 July 2006 at the locality Čiližská Radvaň. In comparison to 2007, it was about 17 days later.

Table 3. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2007; Localities Sokolce and Čiližská Radvaň (Slovakia)

Tabuľka 3. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2007; Lokality Sokolce a Čiližská Radvaň (Slovensko)

Stage	Sokolce*				Čiližská Radvaň*			
	20 June		04 July		20 June		07 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.00	± 0.00	0.00	± 0.00	0.75	± 1.50	0.00	± 0.00
The second instar larvae	24.00	± 6.22	0.00	± 0.00	13.25	± 3.40	0.00	± 0.00
The third instar larvae	63.75	± 14.73	0.00	± 0.00	24.50	± 5.80	1.00	± 0.82
Sum of larvae	87.75	± 14.20	0.00	±0.00	38.50	± 9.40	1.00	± 0.82
Pupae	14.00	± 2.94	1.25	± 0.96	1.25	± 0.96	0.00	± 0.00
Adults	8.00	± 2.94	1.25	± 1.50	2.00	± 1.41	3.00	± 1.41
Total	109.75	± 11.00	2.50	± 2.38	41.75	± 7.54	4.00	± 1.41

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Table 4. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2007; Localities Veľké Chlievany and Rybany (Slovakia)

Tabuľka 4. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2007; Lokality Veľké Chlievany a Rybany (Slovensko)

Stage	Veľké Chlievany*				Rybany*			
	27 June		04 July		27 June		07 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
The second instar larvae	9.25	± 4.03	1.25	± 0.96	0.75	± 0.96	2.75	± 1.71
The third instar larvae	18.50	± 4.80	4.75	± 1.71	22.50	± 4.20	15.25	± 5.44
Sum of larvae	27.75	± 6.60	6.00	± 1.41	23.25	± 4.50	18.00	± 6.98
Pupae	4.00	± 1.83	1.25	± 1.26	0.75	± 0.96	3.25	± 1.26
Adults	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00	2.75	± 0.96
Total	31.75	± 8.22	7.25	± 1.71	24.00	± 4.55	24.00	± 6.78

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Tables 5 and 6 show the numbers of the WCR larvae, pupae and adults in maize root cores at the locality Komoča. The largest number of larvae was found on July 2 and the first larvae were observed on 12. June 2008. In 2009 and 2010, the highest numbers of larvae were found on 27. June.

Together 12.00, 13.25, 24.00 and 6.50 individuals in 40 maize root cores were recorded on 12 June, 19 June, 02 July and 10 July 2008 in Komoča, respectively

(Table 5). The first appearance of adults was ascertained on 2 July 2008, whereas in 2009 and 2010 it was on 27 June (Table 6), which was about 5 days earlier. The largest number of pupae was monitored on 27 June 2009. The pupae were not found in 40 maize root cores on 12 June 2008 (Table 5). At the locality Komoča on 27 June 2009, 0.75 larvae were watched in the first, 5.25 larvae in the second and 27.25 larvae in the third instar in 40 maize root cores. This ratio was changed on 04 July 2009. Together no larvae were found both in the first and second instar, and 2.25 larvae in the third instar. On the other hand, only larvae of third instar were recorded on 04 July 2009. The similar course of development of larval instars was monitored in the next year (Table 6). The years 2009 and 2010 were warm, but 2010 was the rainiest for the last 140 years.

The rainfall and temperature contributed to the earlier development of larvae in 2010, because on 27 June 2010 were situated together 12.75 larvae and on 7 July 2010 only 1.50 larvae at the locality Komoča (Table 6). In this table is possible to see the changes in the development of the larvae and the decrease of the number of younger instars larvae over the time. The same development of larvae over the time is possible to see in Table 5.

Table 5. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2008; Locality Komoča (Slovakia)

Tabuľka 5. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2008; Lokalita Komoča (Slovensko)

Stage	Komoča*							
	12 June		19 June		02 July		10 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
The second instar larvae	4.00	± 1.83	2.25	± 1.50	1.00	± 1.41	1.00	± 0.82
The third instar larvae	8.00	± 2.58	7.00	± 3.27	15.00	± 5.35	4.50	± 2.52
Sum of larvae	12.00	± 2.71	9.25	± 4.57	16.00	± 6.68	5.50	± 2.38
Pupae	0.00	± 0.00	4.00	± 1.41	5.00	± 1.83	0.00	± 0.00
Adults	0.00	± 0.00	0.00	± 0.00	3.00	± 1.41	1.00	± 1.41
Total	12.00	± 2.71	13.25	± 3.50	24.00	± 5.35	6.50	± 3.32

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Table 6. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2009 and 2010; Locality Komoča (Slovakia)

Tabuľka 6. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2009 a 2010; Lokalita Komoča (Slovensko)

Stage	Komoča 2009*				Komoča 2010*			
	27 June		04 July		27 June		07 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.75	± 0.96	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
The second instar larvae	5.25	± 2.63	0.00	± 0.00	1.25	± 0.96	0.00	± 0.00
The third instar larvae	27.25	± 9.60	2.25	± 1.26	11.50	± 3.51	1.50	± 1.00
Sum of larvae	33.25	± 8.62	2.25	± 1.26	12.75	± 3.95	1.50	± 1.00
Pupae	5.75	± 2.63	1.00	± 1.41	3.00	± 0.82	1.00	± 0.82
Adults	2.50	± 1.29	1.75	± 0.96	0.25	± 0.50	1.25	± 1.90
Total	41.50	± 7.23	5.00	± 2.16	16.00	± 4.90	3.75	± 2.22

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each dat; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Table 7 reveals the number of WCR larvae, pupae and adults in maize root cores at the locality Mojmírovce. The results of observation reflect the development of WCR on roots cores.

In average 22.00 and 3.25 individuals were found in 40 maize root cores on 27 June and on 04 July 2014 in Mojmírovce, respectively. At the same locality, together 37.50 and 2.75 individuals in root cores were found on 26 June and on 3 July 2015. As it

possible to see the largest number of larvae was recorded on 26 June 2015 (Table 7). There were observed 4.75 pupae and 3.25 adults of WCR on 27 June 2014. In the next year were watched 6.00 pupae and 3.00 adults of WCR at the same date. The ratio of all three larval instars was decreased in both of year. The number of young larvae drops away over the time. The most of WCR individuals were recorded in 2015 compared to 2014.

Table 7. Number of the western corn rootworm (WCR) larvae, pupae and adults in maize root cores (cubic shape with diameter of 15 cm) at different dates in 2014 and 2015; Locality Mojmírovce (Slovakia)

Tabuľka 7. Počet lariev, kukiel a imág kukuričiara koreňového v koreňoch kukurice (tvar kocky s priemerom 15 cm) v rôznych termínoch v roku 2014 a 2015; Lokalita Mojmírovce (Slovensko)

Stage	Mojmírovce 2014*				Mojmírovce 2015*			
	27 June		04 July		26 June		03 July	
	x	s	x	s	x	s	x	s
The first instar larvae	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00	± 0.00
The second instar larvae	0.50	± 0.58	0.00	± 0.00	1.25	± 0.96	0.00	± 0.00
The third instar larvae	13.50	± 5.92	0.25	± 0.50	27.25	± 7.59	1.00	± 1.15
Sum of larvae	14.00	± 6.06	0.25	± 0.50	28.50	± 8.19	1.00	± 1.15
Pupae	4.75	± 0.96	1.00	± 0.82	6.00	± 3.92	1.25	± 1.50
Adults	3.25	± 1.25	2.00	± 1.83	3.00	± 1.41	0.50	± 0.58
Total	22.00	± 6.48	3.25	± 1.50	37.50	± 9.40	2.75	± 2.22

* Together 40 maize root cores (four repetitions each with 10 cores) were collected and analysed for the WCR larvae, pupae or adults on each date; x = average from four repetitions, s = standard deviation

* Spolu 40 koreňových balov kukurice (štyri opakovania po 10) bolo zhromaždených a analyzovaných na prítomnosť lariev, kukiel a imág kukuričiara koreňového v každom termíne; x = priemer zo štyroch opakovaní, s = smerodajná odchýlka

Discussion

There was a long period of ice days in winter 2005/2006 (SHMU, 2006). According to Chiang (2011) exposure of eggs of the western corn rootworm to winter temperatures, especially if they are below freezing point, reduce their viability. Cooler soil temperatures, especially during the egg-larval periods, caused by insulating soil surface debris may contribute to adult emergence delays observed in reduced tillage fields (Liebhold and Tobin, 2008). During 2006 was found smaller numbers of the WCR individuals at the locality Rybany, compared to the locality Čiližská Radvaň. It was with high probability caused by climatic conditions at both localities. It could be caused also by later sowing date of maize, because Meinke et al. (2009) reported, that delayed planting of maize delays initial adult emergence and reduces total emergence. High rainfall in December 2005 also may affect the frequency of pest during 2006. Seasonality of adult is influenced by availability of moisture, which in turn can be influenced by agricultural practises (Krysan and Miller, 2012). Therefore it can be assumed that winter reduces overwintering eggs at locality Rybany resulted in less number of the WCR larvae in soil.

The results obtained in 2007 showed relation between warm weather and number of WCR found in the soil. The year 2007 was very hot and several temperature records were monitored in Slovakia in this year (SHMU, 2007). It is known that dry and warm conditions generally lead to increasing of insect´s number, but there are limits from which these become negative (Grozea et al., 2009). This statement confirms results of 2007, because there were recorded high number of WCR individuals at all watched localities studied in this year. It was probably the reason of the earlier hatching of the WCR larvae which was followed by earlier development of the other pest stages. Thus, in 2007, maximum of the WCR individuals were found in the second and in the third decade of June. The first emerged adults were recorded on 20 June 2007. The similar situation of earlier development of WCR was recorded in western Romania, where the emergence of *Diabrotica virgifera* adults was observed during second decade of June. There the pupal stage can be observed from the end May and larval stage can be found from beginning of May (Grozea, 2010). In the U.S. Corn Belt, WCR adult emergence may begin in late June to early July with peak emergence often occurring during July (Darnell et al., 2000). In Croatia, initial adult emergence was recorded from 17 June to 02 July during 1998 – 2000 (Bazok, 2001). Peak (50%) emergence has occurred during the first to third weeks of July in Croatia and Hungary (Bayar et al., 2003).

The year 2008 was also extremely warm, but with sufficient of rainfall. In almost all months the average temperatures were above the normal (SHMU, 2008). In fact, during 2008 number of factors could lead to later development WCR, for example, the date of sowing corn, pH and soil type, foregoing crop, the soil floatation during winter, etc. Meinke et al. (2009) also claim, that various factors can affect adult emergence timing, total adult emergence, and size of emerged adults. As shown in results, maximum of individuals and first adult were found on the 02. July 2008. The warm climate, low altitude and soil conditions allow for the complete adult WCR development since the initial decade of July – before the 190th day (09. July) of the year (Středa et al., 2013). Winter 2008/2009 was the coldest of the last three winters. The weather in 2009 was changeable. Spring started later and it was rainy (SHMU, 2009).

In 2009 and 2010, maximum of individuals were found by the end of June and emergence of adults started on 27 June. In Romania, in 2008 the first larvae appeared in the second decade of June, and in 2009 in the first decade, in 2010 appeared probably in late May, beginning of June (Goga and Roșca, 2011). Western corn rootworm larvae were found on 04 June in West Central Indiana (Bledsoe and Obermeyer, 2008).

The year 2010 was warm, but not as warm as the years 2007 and 2008, but it was the rainiest for the last 140 years (SHMU, 2010). When soil is very wet or dry, increasing mortality or decreasing movement can reduce larval establishment (Macdonald and Ellis, 1990). First instars (newly hatch larvae) are particularly susceptible to saturated soil and will die after being denied air for a less than a day (Bledsoe and Obermeyer, 2008).The temperature and rainfall has a very serious influence on WCR flight dynamics in adults. Excessive rainfall leads to decreasing of adult numbers (Grozea et al., 2009). Based on the Števo and Cagáň (2010) observation, no larvae were monitored where soil with eggs was flooded for 28 days. The percentage of larvae collected from the soil decreased with time of duration of soil flooding. Based on these arguments can be said, that rainfall could be responsible for the limited development of the WCR larvae, which could lead to their death for not being able to transport to the roots of corn and feed. This results showed decreasing numbers of WCR individuals on 07 July 2010 in Komoča, thus the lowest during all monitored years at this locality. The presence of the WCR adults is average from beginning June to early September in south Hungary (Komáromi et al., 2010). The first adult flight was registered on 25 June in Serbia (Galo and Sivcec, 2003).

The weather during the vegetation season of 2014 and also of 2015 can be characterised as extremely warm with dry periods (Meteorológia a klimatológia, 2016). Winter 2014 was very warm, which was positive for WCR eggs, because they needs mild winter to survive. The beginnig of larval development depends on the temperature. Warmer temperatures generally lead to higher survival and more rapid development of insects (Haridas et al., 2016). The development of larvae began in both of years earlier, whereas the first pupae and adults appeared at the end of June. The average date that larvae have been first detected in roots during the last 27 years was 31 May in Indiana USA (Bledsoe and Obermeyer, 2008). The adults began to emerge in the second half of July in Ontario and Quebec, Canada (Meloche and Hermans, 2004). Davis et al. (1996) had predicted the presence of pupae and the first adults on 26 June in New York, USA. Every-year occurrence and intensive propagation of WCR can be expected in Danubian lowlands. These climatic regions allow the development and survival of WCR in Slovakia.

Conclusion

All studied years were characterized by abnormal warm weather. This phenomenon could be attributed to global warming, thereby according to this findings can be impute to earlier appearance of WCR, earlier maize seeding, earlier hatching and development of larvae, passing through instars and change to adult. On the basis of the observations of this study, it can be awaited the WCR adult emergence in the last decade of June and in the first decade of July in Slovakia. This research made it

possible to identify the date of emergence of adults. It can be between 27 June and 7 July according to the weather (temperature) in a given year. This information is important for agronomists, whereby they are able to intervene just in time for the WCR. To sum up it could be said, that warm weather, or year has positive effect on development (it speed abundance) of pest, independent of location, respectively. Generally it can be assessed, that warm years and overall global warming is favourable for the western corn rootworm in our country.

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