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Seasonal Fluctuation of *Agriotes lineatus*, *A. obscurus* and *A. sputator* Click Beetles Caught using Pheromone Traps in Poland

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Abstract

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The trap catch of *Agriotes* species and dynamics of the occurrence of adult click beetles using pheromone traps were determined, and the relationship between the dynamics of the caught wireworms and the placement of traps in selected agricultural crops was investigated. The study was conducted in 2011–2014 in the fields of different crops at five localities in two regions in Poland. The effectiveness of trapping the Elateridae beetles using pheromone traps varied in different localities. The results of the analysis of variance indicate statistically significant differences in the number of *A. lineatus* beetles only in individual years of research. On average, most individuals of this species were observed in the first year of observation (72.62), and the least – in 2012 (18.5). Statistically significant differences in the occurrence of beetles in each month were observed for all species except *A. obscurus*. No statistically significant differences between populations of the tested *Agriotes* species were observed in different localities. Their effectiveness was influenced largely by weather conditions. Pheromone traps work well and can be a part of an assessment system for the integrated pest management of *Agriotes* species.

Keywords: *Agriotes* spp.; elaters; forecasting; monitoring; YATLORf traps; IPM

Click beetle larvae (wireworms) have spread in all habitats and can damage a wide range of cultivated plants in fields, vegetable plantations, forests, and garden nurseries. All over the world, the wireworm's harmfulness and also crop protection against this pest are a part of ecology that has been given much attention. Wireworms of the genus *Agriotes* (Coleoptera: Elateridae) are common pests in Poland and cause serious damage to a number of crops. In Poland, wireworms damage particularly basic crops (cereals, including maize, potatoes, beets, grasses). Wireworms, the soil-dwelling larvae of *Agriotes* spp. or click beetles, are ubiquitous pests all over the world (Tóth 1984; Landl *et al.* 2010). The pests feed mainly on roots and tubers of different plant species. They can cause severe damage to cereals (maize, wheat), vegetables, oil crops (sunflowers, rape), sugar beet, grasses and other crops (Subchev *et al.* 2004, 2006; Landl *et al.* 2010; Landl & Glauninger 2013). The larvae are able to destroy up to 25% of crop yields but with root vegetables they mainly reduce the quality of the crop rather than the yield. Potatoes are the most susceptible crop in Poland and around the world (Parker & Howard 2001; Subchev *et al.* 2006; Erlichowski 2008, 2011). Losses in potato cultures caused by the feeding of larvae range usually

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from 5% to 25%, and in extreme cases come up to 50% of the tubers, including those in the unprotected and environment-friendly plantations (Furlan & Tóth 2007).

In recent times, there have been major changes in the structure of plant production in Poland. The number of farms involved in the production of vegetables, potatoes, sugar beet, and cereals has decreased, while the number of farms growing rape and maize has increased. A detailed analysis of selected major crops confirms for example that the occurrence of wireworms and other soil pests is related indirectly to the cultivation of the more and more popular maize for green fodder and biogas (mainly in agricultural monocultures that are conducive to accumulation of pests). Additionally, farmers very often have to deal with the massive presence of the larvae of pests in the soil in connection with the management and use of fallow land and other agricultural land on which some restrictions on the plough cultivation are applied. The treatment against them is often difficult due to the delayed identification and lack of chemicals that can be used during the growing season in the present state of plant protection applicable to the potatoes. Thus, protection against these pests must be properly prepared and preceded by an earlier control of the plantation settlement status. Chemical plant protection measures against wireworms must be highly effective and ecologically safe. The different insecticide applications must take into account the amount of the pest present. The integrated system of plant protection against wireworms (the Elateridae larvae) includes an analysis of the number of larvae in the soil by means of bait or soil pit traps before planting any potatoes or sowing of beets, the use of plant resistance mechanisms and thus the variety susceptibility to damage mechanisms, the application of agronomic tillage (skimming, hoeing, ploughing) and controlling operations of the population size of the wireworms (click beetles) on the plantation during the growing period by means of pheromone traps (Furlan *et al.* 2001; Furlan & Tóth 2007; Erlichowski 2009, 2011).

Until now, the soil excavation, being a labour-intensive method (controlled method), has been used to define the density of wireworms. The use of pheromone traps is the common method of controlling and monitoring these pests. The task of pheromone traps is to allow orientation in the number of beetles, which indirectly affects the number of larvae, as well as monitoring and preparation of control strategies in the future. The traps have been used successfully in a number of European countries (Germany, France, Belarus), the USA and Canada (Vernon & Tóth 2007; Hicks & Blackshaw 2008; Cannaert *et al.* 2011; Vidal *et al.* 2011; Trepashko & Ilyuk 2012).

According to recent surveys, *Agriotes lineatus* (L.), *Agriotes obscurus* (L.), and *Agriotes sputator* (L.) are predominant species occurring in Poland (Jakubowska & Bocianowski 2014), and they live in both agro-systems and natural ecosystems (Platia 1994). Specific synthetic sex pheromones for male trapping have been developed (Toth *et al.* 2003) to monitor the flight behaviour of these species and the recent development of YATLORf traps proved to be highly efficient in capturing male click beetle (*Agriotes*) species (Furlan *et al.* 2001). However, Hicks and Blackshaw (2008) showed that there is a considerable variability in the performance of sex pheromone trapping systems and optimal trap spacing for several *Agriotes* species. In general, pheromone traps have been proven to be effective for monitoring and may have a potential to suppress low density populations. Recent studies on the range of attraction of pheromone traps to some *Agriotes* species suggested that an estimated distance of 20 m between individual traps would be needed to permit substantial mass trapping (Sufyan *et al.* 2011). They are already installed in case of the potato forecrop (1–2 years before the proper cultivation of the potato). As such they are used to monitor the surface of the field in respect of the species of the Elateridae settled there: to determine their number and population dynamics, mainly their seasonal fluctuation (long-term forecasting).

The objective of our study was to compare catches of the three species of the family Elateridae using pheromone traps in different crops, to verify the possibility of their use as a part of the integrated plant monitoring management.

MATERIAL AND METHODS

Experimental site. Monitoring studies on the effectiveness of catching adult Elateridae using pheromone traps were conducted in 2011–2014 by the Institute of Plant Protection – National Research Institute in collaboration with the Warmia and Mazury Agricultural Advisory Centre in Olsztyn in Poland, in the Wielkopolska Province in Winna Góra (52°12'N, 17°27'E), in Słupia Wielka (52°13'N,

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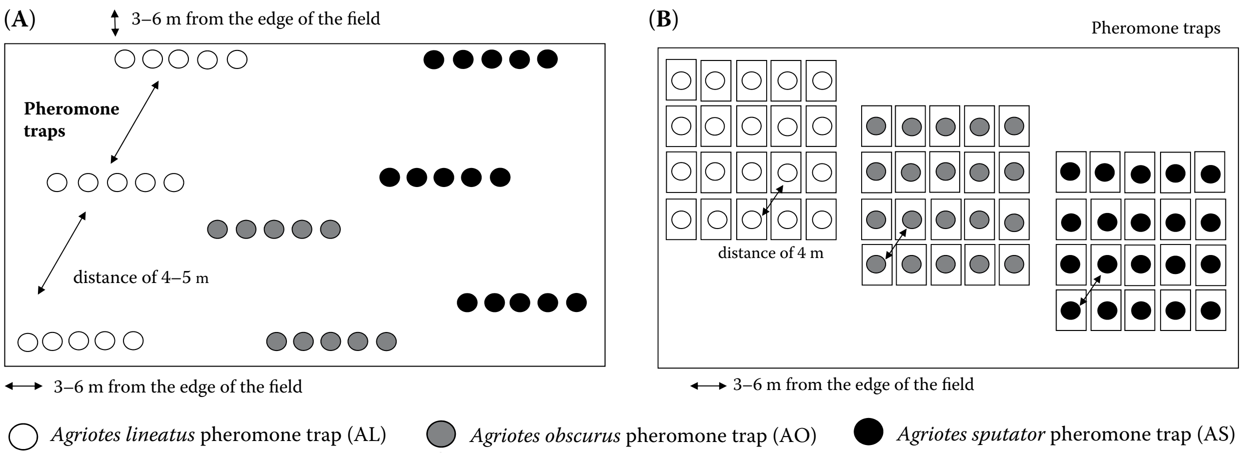
Table 1. Population size of the species from the genus *Agriotes* caught at selected locations in the Warminsko-Mazurskie and Wielkopolska Province in 2011–2014

Year	Location	Crop plant	Total number of traps per field for each species of *Agriotes* spp.	Number of click beetles caught		
				A. lineatus	*A. obscurus*	*A. sputator*
2011	Barczewko	potato	15	–	466	–
	Garzewko	maize	15	–	–	–
	Łęgajny	potato	15	–	117	–
	Słupia Wielka	grasses	20	258	63	0
	Winna Góra	sugar beet	20	323	1	0
2012	Barczewko	potato	15	–	51	–
	Garzewko	maize	15	–	–	–
	Łęgajny	potato	15	–	–	–
	Słupia Wielka	grasses	20	81	17	41
	Winna Góra	sugar beet	20	67	17	0
2013	Barczewko	potato	15	–	163	–
	Garzewko	maize	15	34	0	–
	Łęgajny	potato	15	0	52	–
	Słupia Wielka	grasses	20	388	556	0
	Winna Góra	sugar beet	20	113	46	20
2014	Barczewko	potato	15	8	81	–
	Garzewko	maize	15	23	19	–
	Łęgajny	potato	15	32	5	–
	Słupia Wielka	grasses	20	312	103	372
	Winna Góra	sugar beet	20	148	63	146

(–) not found

17°13'E) in the Warmia and Mazury Region, in Barczewko (53°50'12''N, 20°41'43''E), in Łęgajny (53°49'N, 20°38'E) and in Garzewko (53°50'45''N, 20°16'49''E). Monitoring was performed on different plantations of sugar beet, maize, potato, and perennial grasses. Traps were placed on plantations in five localities (Barczewko, Garzewko, Łęgajny Słupia Wielka, and Winna Góra) every year (2011–2014) from the third decade of April to the third decade of July (Table 1).

Trap description. Hungarian pheromone traps of the YATLORf type were used to monitor the occurrence of the Elateridae from the genus *Agriotes*,



The experimental design scheme with pheromone traps to caught *Agriotes* species set (**A**) on a farmer's field (5 pitfalls in triplicate) in Barczewko, Warminsko-Mazurskie province and (**B**) on an experimental field area (5 pitfalls in four replication) in Słupia Wielka, Wielkopolska province

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with Hungarian pheromone dispensers – for catching males of *Agriotes lineatus*, *A. obscurus*, and *A. sputator* (Tóth *et al.* 2003; Landl *et al.* 2010; Mangen *et al.* 2011; Trepashko & Ilyuk 2012). Pheromones were delivered by Csalomon (Plant Protection Institute, HAS, Budapest, Hungary) and comprised a mixture of geranyl octanoate and geranyl butanoate.

Trapping design. For each of the species of the genus *Agriotes* 5 pheromone traps were installed (for statistical calculations in three or four replications depending on the locations where the experiment was carried out). Fifteen trap points (e.g. 5 pitfalls in triplicate) in the Warminsko-Mazurskie Province and twenty trap points (e.g. 5 pitfalls in quadruplicate) in the Wielkopolska Province were placed on the soil surface at a distance of 3–6 m from the edge of the field. On each plantation covered by the study, 5 traps were placed for each species. The average size of the field was from 1 ha (perennial grasses and sugar beet) to 3 ha (maize, potato, sugar beet). The first set of traps was placed in April 2011. Trapping of the beetles was ended in July 2014. Lures were replaced once a month; traps were emptied every third day, the adults caught were counted and frozen until determination. A distance from the trap replication was about 4–5 meters. The content of altogether 340 traps was analysed in a laboratory. The collected beetles were identified and counted. Their numbers were determined by specialised keys for insects marking (Tarnawski 2000).

Temperature measurements. Weather conditions in the field were monitored throughout the period of the experiment. Meteorological data were obtained from field weather stations installed in the fields or adjacent to the test plantation.

Statistical evaluation. The obtained results specified the population sizes of the *A. lineatus*, *A. obscurus*, *A. sputator* species individually, and the total population size of the *Agriotes*. One-way analyses of

Table 2. Mean values and coefficients of variation of the number of *A. lineatus*, *A. obscurus*, *A. sputator* individuals, and the total number of *Agriotes* spp.

	A. lineatus		*A. obscurus*		*A. sputator*		*Agriotes*	
	mean	*CV*	mean	*CV*	mean	*CV*	mean	*CV*
Year								
2011	72.62	100.06	40.44	192.53	–	–	76.75	113.17
2012	18.50	99.95	7.08	141.10	10.25	109.91	22.83	96.06
2013	44.58	167.18	51.06	198.81	5.00	125.44	68.6	219.78
2014	26.15	156.52	13.55	130.11	64.75	114.46	65.6	154.21
$HLD_{0,05}$	40.35		47.38		43.17		78.7	
Month								
April	16.92	288.83	0.69	362.32	30.5	166.89	19.76	351.52
May	47.67	148.88	58.69	182.72	85.75	115.53	109.06	157.72
June	47.67	93.71	42.94	151.84	21.50	59.40	79.12	96.57
July	36.67	158.22	11.44	89.42	7.00	89.57	38.29	132.72
$HLD_{0,05}$	39.08		43.20		41.96		70.90	
Location								
Barczewko	2.00	141.50	47.56	160.95	–	–	48.06	158.99
Garzewko	7.12	106.88	4.75	89.89	–	–	9.50	89.47
Łęgajny	8.00	84.75	14.50	172.90	–	–	17.17	140.01
Słupia Wielka	64.94	108.81	46.19	219.51	51.62	151.20	136.94	129.13
Winna Góra	40.69	134.09	7.94	130.73	20.75	136.24	59.00	111.64
$HLD_{0,05}$	46.15		56.48		54.51		86.40	
Provinces								
Warmińsko-Mazurskie	6.06	109.24	29.81	195.47	–	–	29.19	187.63
Wielkopolskie	52.81	119.88	27.06	271.66	36.19	162.78	97.97	139.94
$HLD_{0.05}$	25.48		32.21		–		49.50	

CV – coefficient of variation

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variance (ANOVA) were performed independently in order to verify the null hypothesis on no impact of years, months, localities, and provinces individually on the population sizes of *A. lineatus*, *A. obscurus*, *A. sputator* and the total population size of the *Agriotes*. For the considered years, months, localities and provinces, mean values and coefficients of variation (Kozak *et al.* 2013) in the population sizes of individual species and their sums were estimated. Turkey's $HSD_{0.05}$ values (Honestly Significant Differences) were used to test significance of differences in the occurrence of the species of the genus, and the sum of the population size of the *Agriotes* within individual differentiation factors (independently). The correlation between the population sizes of the three species and the sum of the population sizes of the genus *Agriotes* was evaluated based on the respective correlation coefficients (Kozak *et al.* 2010). All calculations for the statistical analyses were performed using the GenStat 15 statistical package.

RESULTS

A total of 4186 *Agriotes lineatus*, *A. obscurus*, and *A. sputator* adults were captured by means of pheromone traps. In the Wielkopolska Region, 40.4% of the click beetles captured were *A. lineatus*; and only a few individuals of *A. obscurus* (20.7%) and *A. sputator* (13.8%) were trapped. In the Warmia and Mazury Province, *A. obscurus* (22.8 %) was the most common species, followed by *A. lineatus* (2.3%). In the period when the study was performed, the weather conditions were very much diversified. The weather conditions were particularly beneficial for the catches of the *Agriotes* in the years 2011 (1228 individuals), 2013 (1372 individuals), and 2014 (1312 individuals) (Table 1). In this period, high temperatures and moderate rainfalls were recorded, which is advantageous for adult beetles to come out and for the larvae feeding (Jakubowska 2011; Sulewska *et al.* 2013). In 2012, due to intensive rainfalls in July, a decreased number of the Elateridae was caught. Based on the monitoring performed by means of pheromone traps, it was confirmed that these devices are very useful for determining the population size of the adult Elateridae in the fields under study. The first Elateridae from the *A. lineatus* species were caught on plantations at the beginning of May, except for 2012 (Winna Góra), when and where beetles were observed in the third decade of April. The peak population size for the species was observed in May and June, and in Winna Góra in 2011, also in July. In the years 2011–2014, the most abundant species, *A. lineatus*, was caught in 2011: in Winna Góra – 323 individuals, in Słupia Wielka – 258 individuals; in 2013: in Słupia Wielka – 556 individuals, in Winna Góra – 113 individuals, and in 2014: in Słupia Wielka – 312 individuals and Winna Góra – 148 (Table 1).

In 2011–2014, the species *A. obscurus* was caught in highest numbers in Słupia Wielka (2014 – 103 individuals; 2013 – 547 individuals on grasses), in Barczewko (2013 – 163 individuals; 2011 – 466 individuals on potato) and in Łęgajny (2011 – 117 in-

Table 3. The mean squares from one-way analysis of variance (for year, month, location and province) between the population sizes of *A. lineatus*, *A. obscurus*, *A. sputator*, and the total number of *Agriotes* spp.

Source of variation	*df*	*A. lineatus*	*df*	*A. obscurus*	*df*	*A. sputator*	*df*	*Agriotes*
Year								
Year	3	8 884*	3	7 438	2	20 484**	3	7 669
Residual	44	3 007	60	4 208	13	2 995	64	11 638
Month								
Month	3	3 566	3	12 378*	3	19 980**	3	27 498
Residual	44	3 197	60	3 965	12	3 152	64	10 708
Location								
Location	4	10 777**	4	6 055	1	7 593	4	34 815*
Residual	43	2 793	59	4 249	14	3 445	63	9 977
Province								
Province	1	36 822***	1	128	–	–	1	80 130**
Residual	46	2 715	62	4 399	–	–	66	10 419

df – number of degrees of freedom; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

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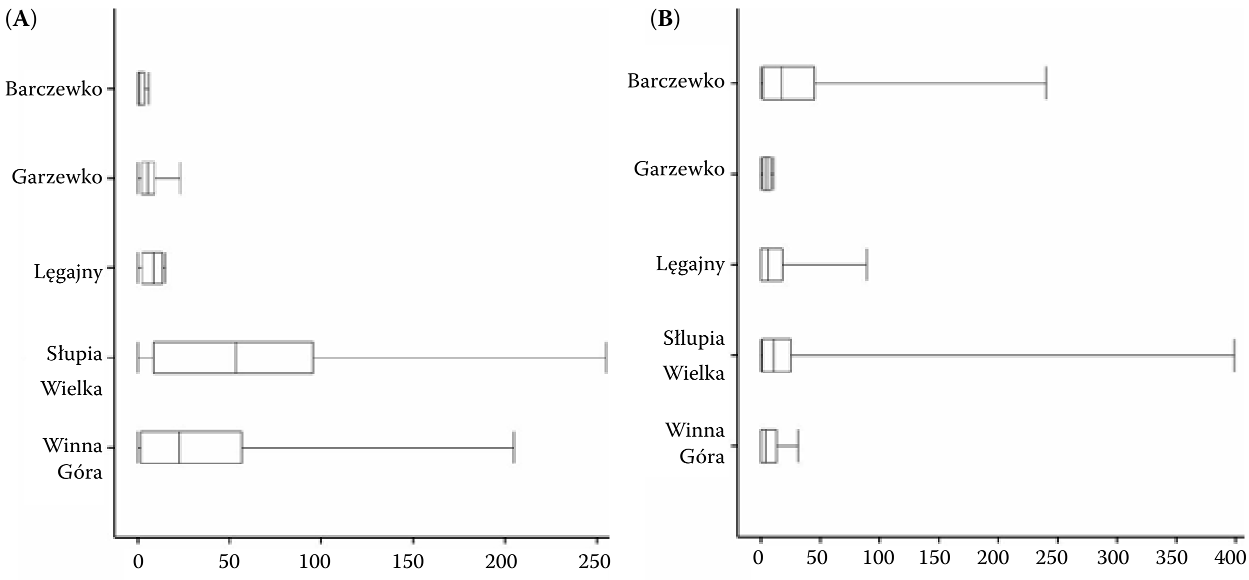

Figure 1. Box-and-whisker plot of the number of (A) *Agriotes lineatus* and (B) *Ariotes obscurus* click beetles classified by the localities under study in 2011–2014

Right and left of the box are the 25th and 75th percentile – the lower and upper quartiles, respectively; the band near the middle of the box is the 50th percentile – the median; the ends of the whiskers represent the minimum and maximum of all the data

dividuals on potato) (Table 1). On the basis of the monitoring carried out by means of pheromone traps, it was identified that of all species only the *A. sputator* click beetle (Table 1) was caught in largest quantities in 2014.

Results of the analysis of variance indicate statistically significant differences in the population sizes of only *A. lineatus* and *A. sputator* in different years of research (Tables 2 and 3). On average, most individuals of this species were observed in the first year of research (72.62), while the smallest number of the individuals was identified in 2012 – 18.5 (Table 2). In case of *A. sputator* most individuals were observed on average in 2014 (64.75).

Statistically significant differences in the occurrence of beetles in individual months were observed for all species except for *A. lineatus*. The smallest number of beetles of all species was observed in April (Table 2 and Figure 2). The beetles of the *A. lineatus* species were most frequent in May and June (47.67), *A. obscurus* – in May (58.69), and *A. sputator* – in May (85.75). All in all, most beetles of the genus *Agriotes* were observed in May – 109.06 (Table 2 and Figure 2).

Statistically significant differences between populations of the tested species of the *Agriotes* were observed in different localities (Table 3 and Figure 1). *A. lineatus* was a dominant species, for which the most individuals were observed in Słupia Wielka locality (64.94), and the smallest number of beetles of this species was observed in Barczewko (2.0) (Table 2).

Based on results of the analysis of variance, it was found that provinces were a factor that determined only the population size of *A. lineatus* (Tables 2 and 3). By far more individuals of this species were observed in the Wielkopolska Province (52.81) than in the Warmia and Mazury Province (6.06) (Table 2).

Table 4. The correlation coefficients between the population sizes of *A. lineatus*, *A. obscurus*, *A. sputator* and the total number of *Agriotes* spp.

Species	*A. lineatus*	*A. obscurus*	*A. sputator*	*Agriotes* spp.
A. lineatus	1			
A. obscurus	0.41	1		
A. sputator	0.58*	0.84***	1	
Agriotes spp.	0.80***	0.81***	0.94***	1

*$P < 0.05$; ***$P < 0.001$

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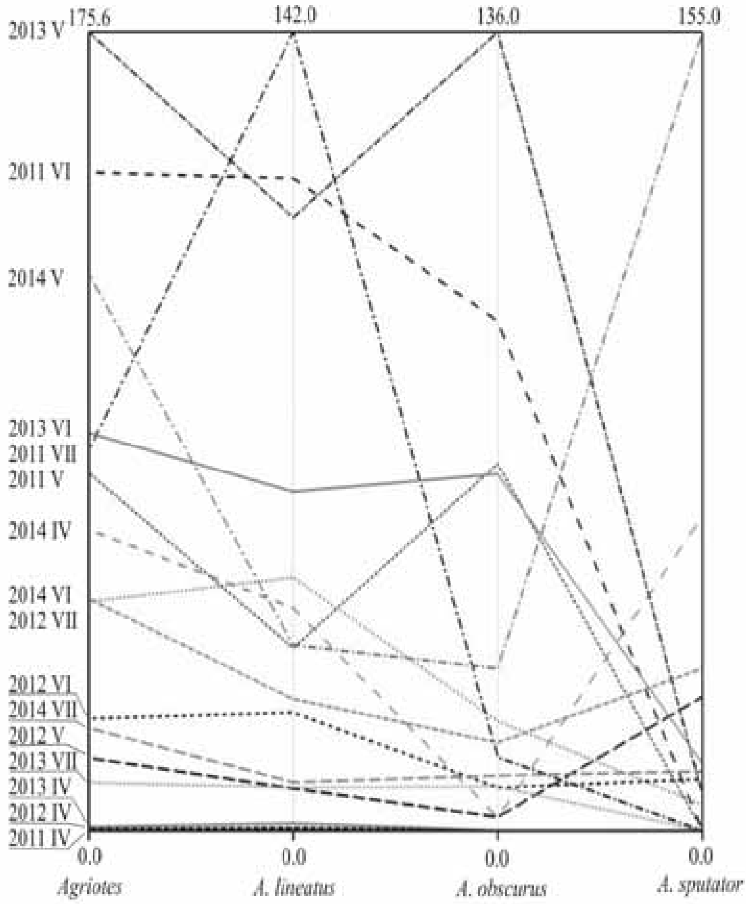

Figure 3. The mean values of the population sizes of *A. lineatus*, *A. obscurus*, *A. sputator*, and the total number of *Agriotes* spp. for the combination "year-month"

The presence of *A. lineatus* individuals was significantly correlated with the occurrence of *A. sputator* individuals (r = 0.58) (Table 4). A preliminary conclusion from the present study postulates that *A. lineatus* and A. *obscurus* were responding in a similar way to the pheromone traps under the same environmental conditions.

DISCUSSION

The *A. lineatus* species spends the winter as adults in the soil (Tóth 1984). We observed the flight of this species from May until late July, which is consistent with the results from Austria (Landl *et al.* 2010), Bulgaria (Subchev *et al.* 2004), Hungary (Furlan *et al.* 2001; Tóth *et al.* 2003), and Romania (Radescu & Roşca 2010). In our study (Jakubowska & Bocianowski 2013), we observed the first *A. lineatus* beetles at the end of April, as they were observed by Radescu and Roşca (2010) in Bucharest (Romania) and Trepashko and Ilyuk (2012) in Minsk (Belarus). Our overall observations show that the number *Agriotes* adults varies according to different localities and years (Landl *et al.* 2010; Radescu & Roşca 2010; Erlichowski 2011), but is similar if climatic conditions are comparable. Our current observations correspond to the results presented by Jakubowska (2011) as well as Sulewska *et al.* (2013). These authors reported that all species of the tested wireworms were caught most frequently in the years 2010 and 2011. Benefer *et al.* (2012) reported that in the years of the study, the weather conditions were very varied and that had an especially positive impact on the wireworm development in 2011–2012. This is also confirmed by our own research.

The monitoring performed by means of pheromone traps proved the presence of the three species of the click beetle under study from the genus *Agriotes* in sugar beet, potato and seed-bearing grasses. *Agriotes obscurus* was the most abundant species (Table 1). Its dominance was observed in 2011 and 2014. Both our own research (Jakubowska & Bocianowski 2013) and Landl and Glauninger (2013) as well as Hicks and Blackshaw (2008) proved that weather conditions prevailing in the growing seasons have

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an important influence on the occurrence of the Elateridae. Moreover, according to different authors, the largest number of the caught species of the wireworms is affected by the position of traps in the fields of different vegetables and agricultural crops as well as in grassland surrounding the plantations.

Furlan and Tóth (2007) believe that monitoring of the number of beetles by means of pheromone traps is an important link in providing information in integrated systems for the potato cultivation, assessment of the risk of damage, biology and behaviour of the pest. Sufyan *et al.* (2011) and Benefer *et al.* (2012) examined the dynamics of occurrence of two species: *A. lineatus* and *A. obscurus* on an organic potato plantation and they also assessed the effectiveness of catching a group of marked (male) beetles depending on the distance from the trap. This may explain the discrepancies observed in the population size between the examined species. Recent findings on the range of attraction of pheromone traps to *A. lineatus* and *A. obscurus* have shown that up to a distance of 15 m from the traps at least 50% of the males have been trapped within one month, most of them already during the first days (Sufyan *et al.* 2011).

In our study, the flight peak reached for *A. lineatus* and *A. obscures* beetles in traps was observed in May. These values are comparable with those reported by Sufyan (2011). The flight peaks of *A. lineatus* differed between the years. *A. obscurus* showed a flight pattern comparable to *A. lineatus* during the swarming period. In the present study, the percentage recapture of *A. lineatus* was higher than in *A. obscurus* in years (2011, 2012, and 2014) and localities. A higher percentage of caught beetles of *A. obscurus* was observed in 2013. These values are comparable with those reported by Hicks and Blackshaw (2008) with total recaptures of 39% (*A. lineatus*) and 27% (*A. obscurus*). The development of insects is strongly affected by weather conditions (Hicks & Blackshaw 2008; Benefer *et al.* 2012) and it is suggested that climate changes have the potential of affecting their future population dynamics and intensity in agricultural systems. In our study, no clear relationship between weather conditions and the first flight peak could be observed. The available data include a period of four years only, which may be a too short period to evaluate to what extent the temperature affects flight behaviour. However, during this short period of the study there were some fluctuations in weather noted in trap catches. There were no indications that weather conditions (temperature and precipitation) have a decisive effect on the size of trap catches.

According to many authors (Neuchoff & Sufyan 2008; Erlichowski 2009; Mangen *et al.* 2011), forecasting of the damage caused by the Elateridae larvae on the basis of the number of beetles caught using pheromone traps should be treated with caution for the plantation.

The use of sex pheromone traps for mass trapping has been successfully applied for the eradication of a range of agricultural pests before reproduction or crop damage (El-Sayed *et al*. 2006). With respect to any approach targeted on preventing mating via mass trapping of males, accurate knowledge of the range of attraction of the pheromone traps is indispensable. The results obtained in the present study provide an approximate estimation of the trap density required to remove male beetles from the field, assuming that all captured beetles will not have mated. In general, sex pheromone traps have been proven to be effective for monitoring click beetles, which may be an option for controlling wireworms, their dynamics and biology.

CONCLUSIONS

(1) The results from the present study have important implications regarding how we use pheromone traps for monitoring click beetles.

(2) The obtained results will allow to improve methods of short-term and long-term forecasting for the chemical control of wireworms.

(3) Pheromone traps work well and can be a part of an assessment system for the integrated pest management of the *Agriotes* species.

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