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Larval development of *Agriotes obscurus* under laboratory and semi-natural conditions

Muhammad SUFYAN[1], Daniel NEUHOFF[1], Lorenzo FURLAN[2]
[1]*Institute of Organic Agriculture, University of Bonn, Germany*
[2]*Veneto Agricoltura, Legnaro PD, Italy*

Abstract

The biology of the click beetle *Agriotes obscurus* (L.) (Coleoptera Elateridae) including adult morphology, fecundity, larval and pupal development was studied in a climate chamber at a constant temperature of 20 °C and under semi-natural conditions in an outdoor rearing cage close to Bonn, Germany. The eggs of *A. obscurus* were deposited either individually or in clusters of 2 to 39 individuals mostly in May. At a constant temperature of 20 °C, embryogenesis took 22.5 days on average and the percentage of egg hatchability was 95-100%. Head width of the larvae ranged from 0.2 mm (L1) to 1.46 mm (L11). In the laboratory, the larvae passed through 8 to 11 instars during an 18 month period, while in the rearing cage up to 13 instars were recorded over a 30 month period with the life cycle not fully completed at the end of the experiment. In the climate chamber, the larvae reached either instar stage L7 (35%), L6 (32%) or L5 (24%) at the end of the first year. In the rearing cage in contrast, 70% of the larvae reached L5 only at the end of the first year. After the second year, the average larval stage was similar (L10) under both laboratory and field conditions. However, under laboratory conditions at 20 °C, approximately 14% of the larvae had transformed into adults after 14 months, hence completing their life cycle with only one overwintering. Cultural practices to control wireworms in sensitive crops should consider the phases of larval development and adapt soil tillage and crop rotation accordingly.

Key words: click beetle, wireworm, life cycle, biology, pest management.

Introduction

Click beetles (Coleoptera Elateridae) are a serious pests that occur worldwide in both agricultural and natural ecosystems (Platia, 1994). Due to their high fecundity rate, overlapping generations, polyphagous nature, adaptation to a variety of agricultural ecosystems and capability of surviving in various environments the pest is difficult to control. Adult click beetles may live for a few days or up to one year depending on species (Furlan, 2005). The larvae of several *Agriotes* species, generally known as wireworms, damage field crops in Europe and North America (Blackshaw and Vernon, 2008). They primarily feed on plant roots (Vernon and Päts, 1997; Parker and Howard, 2001). *Agriotes* species in Europe have long live cycles, with larvae spending significantly more than one year in the soil prior to pupation (Ford, 1917; Roberts, 1919; Furlan, 1998; 2004).

According to a recent survey, the most abundant species in Germany are *Agriotes lineatus* (L.), *Agriotes obscurus* (L.), *Agriotes sputator* (L.), *Agriotes sordidus* (Illiger) and *Agriotes ustulatus* (Schaller) (Burghause and Schmitt, 2011; Vidal *et al*., 2010; 2011; Vidal and Petersen, 2011) confirming earlier observations (Furlan *et al*., 2001; Toth and Furlan, 2005). Previous studies on *A. obscurus* were focused on aspects of biology and distribution of adults and larvae mainly in arable land (Ford, 1917; Roberts, 1919; 1921; Brian, 1947; Parker and Howard, 2001; Toth *et al*., 2003; Hicks and Blackshaw, 2008; Schallhart *et al*., 2009). Ford (1917) divided the larval development stages of *A. obscurus* in the categories small, medium and large. Roberts (1919; 1921) examined only a few *A. obscurus* specimen and distinguished eight larval stages during the life cycle. In contrast to the biology of *A. sordidus* and *A. ustulatus*, which have been described extensively, focusing on morphological and biological parameters of their development (Furlan, 1998; 2004), currently only few biological data on *A. obscurus* is available. Accurate knowledge on the biology of click beetles including indications on the duration of the different larval stages is a prerequisite for efficient control. Specific knowledge on vulnerable stages of larvae is especially relevant for organic farming, where the use of synthetic pesticides is prohibited.

In the present work, we studied the biology of *A. obscurus* in order to identify potential approaches for non-chemical control and generally for a proper implementation of IPM. We focused on the whole life cycle of *A. obscurus*, including oviposition, larval development and pupation. The life history of *A. obscurus* was studied in a climate chamber at constant temperature of 20° C and in a rearing cage under semi-natural conditions in the field.

Materials and methods

Study area

The study was conducted from 2008 to 2010 at the experimental station Wiesengut close to the University of Bonn, Germany. The mixed farm located in the Sieg river valley has been managing with organic practices since 1986 and is known to be a favourable breeding habitat for *A. obscurus*, *A. lineatus* and *A. sputator*. The alluvial soils have a loamy-silty to sandy-silty texture with an average pH of 6.1 (0-30 cm depth) in the range of arable land. The climate is comparatively mild with an annual average temperature of 10.3 °C. Average annual precipitation is about 770 mm. During the experi-

ment, the soil temperature at 10 cm depth was continuously recorded in the rearing cages in order to calculate the heat sum above 9 °C, since *Agriotes* species show no or only slow larval development below this temperature (Furlan, 1998; 2004).

Adult and egg collection

Click beetles were collected in March 2008 and 2009 by installing forage traps (2 × 2 m plastic nets) on bare soil known to be infested with *A. obscurus*. The sheets were covered with fresh forage of ryegrass (*Lolium* spp.) and/or other grasses and red-clover (*Trifolium pratense* L.) and were inspected at least twice a week and adult click beetles collected. Beetles were sexed by carefully examining abdomen and genital organs with a binocular microscope. Body parameters including abdomen width close to prothorax and length were measured with vernier calipers. After every inspection and collection, the forage was replaced. The collected beetles were stored at 20 °C in boxes filled in with grass leaves and moistened paper to maintain humidity. The experiments started after a maximum of 10 days in captivity.

Specimens collected in March 2009 were transferred to plastic boxes (18 × 12 × 9 cm) half-filled with moist soil and covered with fresh grass leaves at the beginning of April. Each of the 6-10 boxes consisted of groups of 10-15 males and 5-10 females dependent on the amount of adult catches. The boxes were ventilated with 2 mm mesh plastic net lids. Grass leaves and soil were daily replaced and the boxes were thoroughly screened for eggs every day for a period of 15-20 days. All eggs detected were removed and counted by using a spoon and tweezers. The eggs were then measured and transferred into plastic bags with moist soil and kept at 20 °C. After one week, eggs were transferred to different bags to monitor and record the number of hatched larvae and hatching time at regular intervals (at least once every two days).

Climate chamber experiment

The experiment was carried out in vials in a climate chamber kept at a constant temperature of 20 °C from March to November 2009. The larvae were then removed from the climate chamber to overwinter outside (diapause) from November 2009 to April 2010 before starting again with the experiment until November 2010.

To assess starvation resistance 40 newly hatched larvae were placed (3 specimens each) in vials (2.7 cm in diameter and 9.2 cm high) half filled with moist sandy soil. Larvae were kept without food for a period of five weeks and monitored for survival rates every day.

Likewise, for the assessment of the larval stages a total of 202 larvae were transferred to vials (3 individuals per vial), half-filled with moist sandy soil. Before the transfer, 5-8 seeds of *Lolium multiflorum* L. were sown in each vial to feed the larvae. Larvae were measured every 10-15 days (head width, length and exuviae) using DISKUS software microscopic system (www.hilgers.com). At every assessment date soil and seeds were replaced. The life cycle was monitored until the beginning of November of each year, when the outdoor soil temperature dropped below 10 °C.

Larvae in the vials that had not pupated before winter were put into closed tubes and buried in the open field (60-80 cm depth) to trigger diapause and to protect them from frost during the winter season. Vials were taken out in spring when soil temperature climbed above 10 °C and were again transferred to the climate chamber for continuing the experiment.

Field studies under semi-natural conditions

To create semi-natural conditions, a wooden rearing facility was constructed on the soil surface at the border of an open field creating a closed system with outdoor climate conditions. The cage top (area: 1 m^2; height: 1 m) was closed with a 2 mm synthetic mesh screen. The subterranean part was encased with a wooden frame up to 1 m and open at the bottom. The cage was filled with *A. obscurus* free soil and sand in a 1:1 ratio. A range of crops including maize, grass, clover, mustard and wheat were successively grown in the cage during the experiment to feed the larvae.

Depending on the amount of forage trap catches, groups of 50-100 adult males and females (1:1 ratio) were successively released into the cage from early April to mid-May 2008 (in total 175 pairs of beetles). The eggs were periodically inspected from late April until late June in different parts of the cage by carefully sampling the upper soil layer and screening the samples with a binocular microscope.

Larval development in the rearing cage was assessed by collecting larvae using soil samples and bait traps and measuring head width and length. Annual soil sampling started in June 2008, and May 2009 and May 2010, by taking two soil cores (6 cm diameter × 25 cm depth) twice a month. The soil cores were hand-sorted for 1-2 hours, to extract larvae. The head width of the larvae was assessed with the same method mentioned above and specimens were subsequently assigned to their corresponding instar classes determined in the lab trial. Measured larvae were returned to the cages on the same day. After the measurement, the entire soil material including larvae was returned to the cage. To avoid crop disturbance and potential killing of the larvae during collection, soil sampling was substituted by two bait traps (Chabert and Blot, 1992) from July 2008. Bait traps consisted of plastic pots, perforated at the bottom and filled with vermiculite, 30 ml of wheat seeds and 30 ml of corn seeds. The moistened pots were covered with a plastic lid and placed slightly below the soil surface. Every 10 to 15 days traps were inspected and material was replaced. Since the bait traps were assumed to catch wireworms in the feeding phase only (Furlan 1998; 2004), parts of the population may have been missed.

Statistical analysis

Descriptive data on insect biology were amended with mean, median, standard deviation and minimum and maximum values. The parameters ‘larval head width’ and ‘instar duration’ were submitted to one-way analysis

Table 1. Size of *A. obscurus* male and female adults (4-6 weeks old). Data obtained by measuring 300 specimens collected at the experimental farm Wiesengut, Hennef, Germany, between 2006-2009, SD = standard deviation.

	Length (mm)				Width of abdomen close to prothorax (mm)			
	Mean	SD	Max.	Min.	Mean	SD	Max.	Min.
Male	8.97	0.50	10.39	6.79	2.86	0.22	3.49	1.75
Female	9.36	0.52	11.32	8.62	2.97	0.20	3.67	2.63

of variance (ANOVA). Means were subsequently separated using the Tukey Honestly Significant Difference (HSD) test. calculated by SAS (version 9.1, SAS Institute, Cary, NC, USA).

Results

Adult morphology

Adults of *A. obscurus* were dark-brown with no colour dimorphism. The pronotum was wider than long and appeared rounded. Elytra were covered with yellow-grey hairs. Rows of pits formed ridges down the length of the elytra in pairs and displayed a darker brown compared to the rest of the elytra. The antennae were slightly longer than the aggregated length of head and pronotum. Females were on average longer by 0.39 mm and wider by 0.11 mm than males (table 1).

Life cycle under laboratory conditions

Oviposition, egg morphology and distribution

Female beetles started oviposition a few days after introduction (April) into the plastic boxes. The newly deposited eggs were usually elliptic with an average length (n = 150 eggs) of 0.57 mm (SD = 0.04, max. 0.75 mm, min. 0.46 mm), while average width was 0.48 mm (SD = 0.04, max. 0.57 mm, min. 0.39 mm). The eggs were creamy white to grey brown with a smooth sticky surface often covered with sand grains (figure 1), but also irregular in shape and size, presumably due to soil resistance against the ovipositor. They maintained the same colour and shape just until a few hours before hatching and larval emergence. Prior to hatching, the red-brown mandibles of the developed larvae became visible under the egg shell. Eggs decreased in size or failed to develop when put in dry soil, presumably due to a lack of moisture. Eggs were deposited singly or in clusters that consisted of 2 to 39 eggs with batches laid close to each other. Most eggs were laid in the upper 2-3 cm of soil provided that the soil was moist. Some eggs were laid on the soil surface when the soil was covered by grass mulch.

Embryonic development and egg viability

At a constant temperature of 20 °C, the egg stage lasted on average 22.5 days (248 degree days above a base of 9 °C) ranging from 17 to 25 days. Egg viability and hatchability ranged from 95-100% based on more than 300 observations. Newly hatched larvae were whitish in colour with an average length of 2.32 mm ranging from 1.89 to 2.70 mm (figure 2).

Figure 1. Egg clutch of *A. obscurus* in a plastic box filled with moistened soil.

Figure 2. Newly hatched larva of *A. obscurus.*

Larval development and morphology

In the climate chamber, eight to 11 larval instars were noted for *A. obscurus* over a period of 18 months (table 2). The head widths of the various instar stages showed a considerable variation, sometimes resulting in difficulties to distinguish accurately between the different larval stages. However, the mean head width of every instar stage was significantly different from each other (table 2). The average head width increased from 0.2 mm (L1) to 1.46 mm for instar stage L11. Larvae of the first instar (L1) were always recognized by the fact that the pits of the ninth abdominal segment could not be detected even under high microscopic magnification.

Larval stages were noted to overlap during most of the assessment dates up to a maximum of 4 instar stages. In the first year, a gradual increase of the average larval

Table 2. Head width and body length of *A. obscurus* larvae examined over 2 years at constant temperature of 20 °C in vials. Means followed by different letters are significantly different, Tukey-Test (α = 0.05). Mortality rate (%) calculated from the number of remaining specimens from total for each instar.

Instars	Average length (mm)				Head width	No. of	Mortality rate
	Mean	SD	Max.	Min.	(mm)	specimens	(%)
L1	0.20 a	0.016	0.23	0.17	3.66	202	0
L2	0.27 b	0.023	0.33	0.23	4.60	132	35
L3	0.34 c	0.039	0.46	0.27	5.88	114	44
L4	0.43 d	0.061	0.62	0.32	8.00	105	48
L5	0.55 e	0.078	0.78	0.39	9.47	99	51
L6	0.70 f	0.103	1.00	0.45	11.80	96	52
L7	0.87 g	0.151	1.34	0.58	14.19	91	55
L8	1.05 h	0.156	1.45	0.71	17.43	91	55
L9	1.26 i	0.158	1.53	0.91	20.36	87	57
L10	1.37 j	0.158	1.63	1.06	19.95	85	58
L11	1.46 k	0.129	1.67	1.26	22.03	85	58

instar stages was recorded at all assessment dates, while in the second year the overlapping resulted in some younger larval stages appearing at later assessment dates (figure 3). At the end of the first year, the larvae reached either instar stage L7 (35%) or L6 (32%) or L5 (24%). At the end of the second year, the larvae were on average in larval stage L10. The highest instar stage under laboratory conditions (L11) was recorded in June, September and October of the second experimental year (figure 3). Approximately 14% of the larvae completed the life cycle in 14 months with only one overwintering.

The heat sum required to complete the development of individual instar stages increased with larval age with the exception of L8 and L9 (table 3). The final instar (L11) required about eight times more degree days (1,587 DD) than L1 (190 DD). The total heat sum required in the laboratory to complete all larval phases was on average 9,248 degree days above a base of 9 °C.

Larval moulting

The larvae stopped feeding before moutlting (7-10 days) and after moulting (2-3 days) due to body trans-

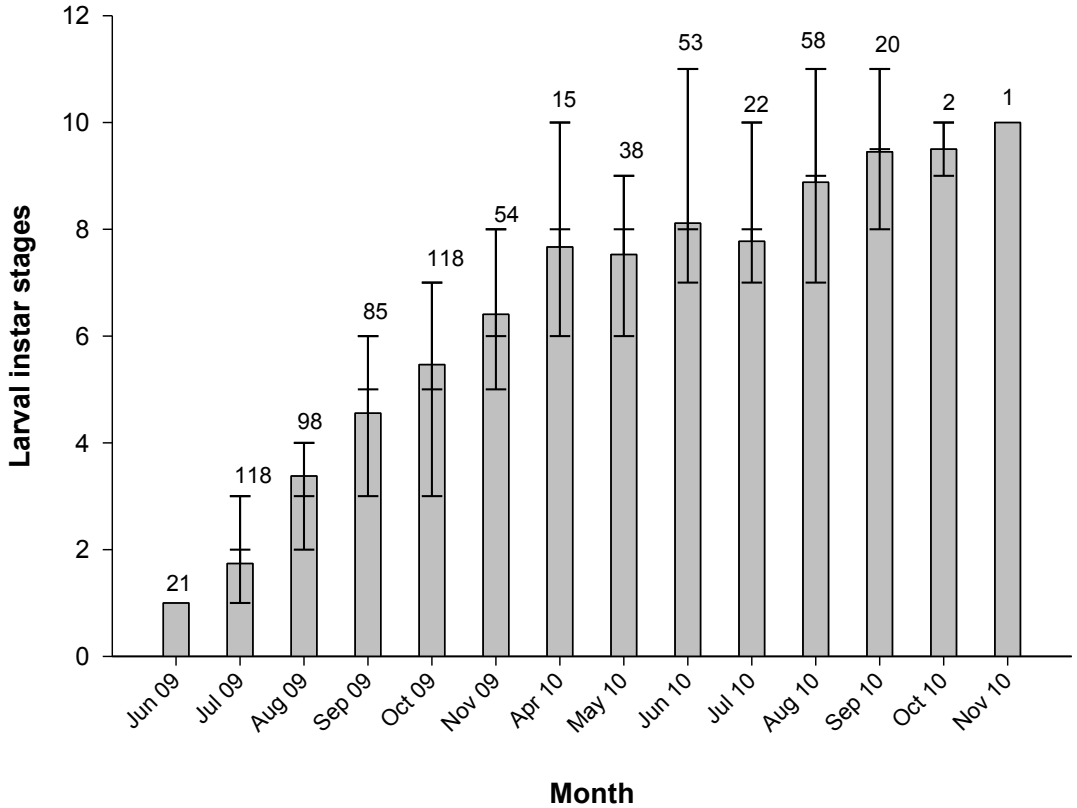

Figure 3. Development of larval instars of *A. obscurus* over an 18 month period at constant temperature (20 °C) in vials. Columns represent the mean larval stage at the end of each month, error bars represent minimum and maximum instar stages with the median (transversal bar), numbers above the columns indicate the sample size.

Table 3. Duration of *A. obscurus* larval instars at constant temperature (20 °C) in laboratory, mean duration in days and average day degrees above a base of 9 °C (heat sum), SD = standard deviation.

Instars	Days				Heat sum	No. of
	Mean	SD	Max.	Min.	> 9°C	specimens
L1	17.3	1.36	18	15	190	202
L2	25.5	10.11	48	18	281	132
L3	46.9	15.73	89	33	516	114
L4	65.8	17.64	113	46	723	105
L5	83.3	16.82	109	45	917	99
L6	100.9	34.48	153	24	1110	96
L7	98.3	43.39	153	34	1082	91
L8	67.7	35.21	137	29	744	91
L9	83.5	31.65	120	37	919	87
L10	107.2	19.49	133	80	1179	85
L11	144.3	7.50	148	133	1587	85
Total	841		1221	494	9248	

Figure 4. Eclosion of *A. obscurus* larva; head and thorax emerged first with the help of pygopodium (dorsal view), bar represent 1.00 mm.

Table 4. Development rate and degree days above a base of 9 °C for *A. obscurus* pupae to adults under laboratory conditions.

	Days	Degree days
Mean	15.4	169.5
SD	2.15	23.67
Max.	20	220
Min.	13	143

formation. The larval body gradually increased in size by absorbing water with an appearance of white bands on either side of the body some time before moulting. At this stage, the larvae slowed down their movement and formed a cell to initiate moulting. During moulting, the skin split along the tergal suture of the head and thorax first, followed by the emergence of thorax, caput, legs and abdomen (figure 4). The exuviation process lasted about 10-15 minutes. Newly emerged larvae started to pucker and flatten for a few minutes before burrowing into the soil.

Larval survival

All larvae (n = 40) died without food within 4-5 weeks after hatching, indicating a low resistance to starvation of newly hatched larvae. Besides, cannibalism was observed between older and younger instars when food was scarce (in those vials where seed germination failed). Under standard conditions the mortality of L2 larvae was 35% rising to 48% in L4. Approximately 55% of the larvae died before the first overwintering. Larval mortality tended to be lower in the second year (table 2).

Pupae

Pupae were milky white in colour and transforming into a light yellow colour just before changing into adults. In the final stages of pupal development, the eyes darkened and became more visible. At 20 °C constant, the development from pupae to adults lasted 15.4 days on average. The average heat sum required to complete pupal development was about 169.5 degree days above a base of 9 °C (table 4). Newly emerged adults were inactive (4-5 days) and the body darkened within 4-5 days.

Life cycle under semi-natural conditions in a rearing cage

Eggs

The first deposited eggs in the rearing cage were observed in late April 2008. Peak oviposition occurred between early May and early June. Females began to lay eggs about 15-20 days after the release of adult beetles into the rearing cage.

Larval population density in rearing cage

In total 341 larvae were collected and assessed by bait traps during the study period from 2008 to 2010. The highest annual number of larvae (284) was recorded in the second year (2009), followed by 38 wireworms in 2008 and 19 wireworms in 2010 (table 5). The highest monthly number of larvae was recorded in June 2009 when 111 individuals were captured, followed by 44 wireworms sampled in August 2009.

Larval development

Under semi-natural conditions, up to 13 larval instar stages were recorded during the 30 month assessment period within which the cycle was not completed. The larval stage at the end of the first year ranged between

Table 5. *A. obscurus* larval development in a field rearing cage cropped with maize, wheat, mustard and grass-clover over the period of 2008-2010. Data are sum of two bait traps in one cage.

	Larvae/ cage	Percentage of total larvae per instar													Heat sum > 9°C	
		1	2	3	4	5	6	7	8	9	10	11	12	13	Soil	Total
June 2008	5		100												*	
July	7		29	71											*	
August	0														*	
September	6			33	67										*	
October	20			20	5	70	5								*	
May 2009	39				10	67	23								186	186
June	111			5	22	58	15								237	423
July	35					11	26	49	11	3					321	744
August	44					7	18	30	43	2					337	1081
September	24					4	4	8	17	46	4	17			224	1305
October	24						4		17	42	21	8	4	4	98	1403
November	7								15	57		14	14		25	1428
May 2010	0														95	1523
June	10						10	40	30	20					204	1727
July	0														308	2035
August	5								60	40					261	2296
September	2									100					183	2479
October	2										100				73	2552

* soil temperature data not available.

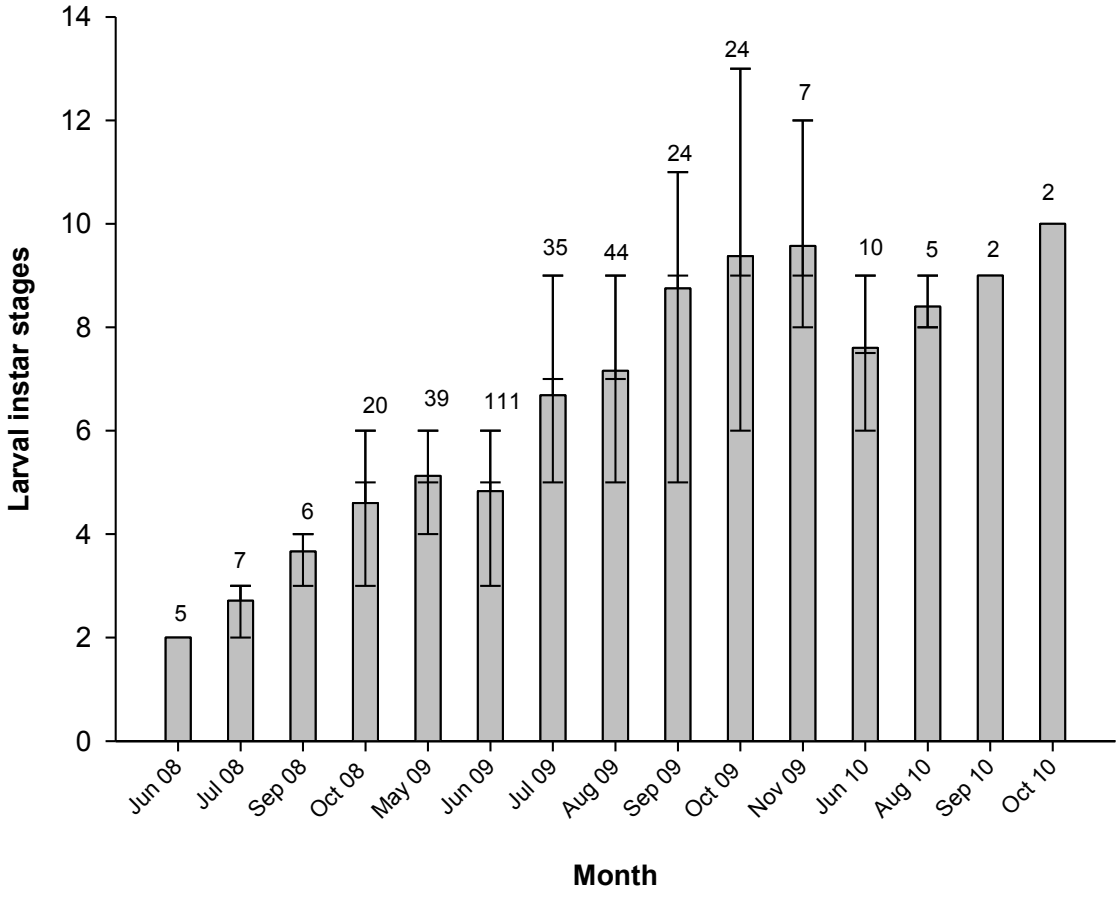

Figure 5. Development of larval instars from *A. obscurus* over a 30 months period under semi-natural conditions in outdoor rearing cages. Columns represent the mean larval stage at the end of each month, error bars represent minimum and maximum instar stages with the median (transversal bar), numbers above the columns indicate the sample size.

L3 to L6 (figure 5). The majority (70%) of the larvae overwintered in L5 followed by 20% in L3 (table 5). The larvae had a length of 8 mm on average prior to the first overwintering. The variability of the larval length of similar instars and the diversity of instars was visible at every single assessment date. In the second year, the majority of the larvae passed through the instar stages L5-L9. Larval stages overlapped at most of the assessment dates with a maximum range of 7 instars noted in October 2009 (figure 5). The highest instar stage ever noted (L13) was recorded in October 2009 during the second year of development. Larvae of the instar stages L8 to L12 entered into a second overwintering and exceeded 18 mm length. Larval stages assessed at the beginning of the third year were similar to those in the second year.

Discussion

Findings of this study showed that a part of the specimens of *A. obscurus* were able to complete a single generation (from egg to adult) in 14 months in a climate chamber at 20 °C and beetles had a period of about four months for adult activity and oviposition. Empirical data on oviposition and larval development are particularly useful when looking for cultural control options, e.g. by adapting soil tillage and crop rotation.

Oviposition

The first eggs of *A. obscurus* were found in April independent of the rearing system. Earlier oviposition however, cannot be completely excluded since in the present study, adults were only collected in April and may have been active before. In contrast to our findings, the oviposition of *A. obscurus* started one to two months later (May and June) in investigations carried out in the UK (Ford, 1917; Roberts, 1919; 1921; Cohen, 1942; Evans and Gough, 1942; Brian, 1947) and Poland (Chrzanowski, 1927). Studies of wireworm populations (*A. obscurus*, *A. lineatus* and *A. sputator*) in UK reported egg seasons from the end of June until the middle of August (Salt and Hollick, 1944), confirming the dominant impact of temperature on egg oviposition and hence larval development.

The oviposition patterns of *A. obscurus* observed in our study (single and small clusters) are in accordance with earlier studies carried out in the UK (Roberts, 1919; Miles, 1942). In the current study, a maximum of 39 eggs of *A. obscurus* were counted in a cluster compared with 52 eggs reported by Roberts (1919). Likewise, in Italy *A. sordidus* tended to lay eggs in batches of 3 to more than 30 (Furlan, 2004). On the basis of our data it is not possible to indicate the total number of eggs laid per female, since the females were captured in fields in advance and may already have oviposited before. For *A. obscurus* Miles (1942) recorded 40-100 or more eggs per female, Chrzanowski (1927) 112-127, Langenbuch (1932) 119, Subklev (1934) 217-237, Brian (1947) 30-150 with a significant effect of crop species on progeny. For *A. ustulatus* the total number of eggs per female was 52-140 (Furlan, 1996).

In our study the majority of wireworms hatched in May and the percentage egg hatchability was 90 and 100%. A similar amount of hatching eggs (95-100%) was recorded for *A. ustulatus* in Italy (Furlan, 1996). In our experiment, embryogenesis of *A. obscurus* at 20 °C lasted 22.5 days on average, while it was 4-6 weeks in the UK (Ford, 1917; Evans and Gough, 1942; Miles, 1942) compared to 23.9 days at 20 °C and 12.6 days at 29 °C for *A. ustulatus* in Italy (Furlan, 1996).

Larval development

Under laboratory conditions, in total 8-11 instars were identified for *A. obscurus* based on the number of moults and frequent measurement of larval body parameters. In contrast up to 13 instars for *A. obscurus* were observed under semi-natural conditions, where newly moulted larvae with head sizes of 1.57 mm (L12) and 1.65 mm (L13) were detected in the bait traps. Our findings are in contrast to Roberts (1921) and Klausnitzer (1994), who indicated only eight instar stages, and the classification of Ford (1917). Higher numbers of larval instars were reported for *A. sordidus* (8-13) and *A. ustulatus* (11-13) at a constant temperature of 25 and 29 °C in Italy (Furlan, 1998; 2004) again, confirming earlier studies with 14-15 larval instars for other *Agriotes* species (Kosmacevskij, 1955). The total number of larval instars of *Agriotes* species is likely to be influenced by intrinsic and extrinsic factors.

Under semi-natural conditions, the larvae reached instar stage L5 on average during the first year, covering a range of L3 to L6. Evans (1942), in contrast, recorded only 2 or 3 moults during the first growing season. Accordingly, the duration of the life cycle for this species varies between different climatic regions. Ford (1917) and Roberts (1919) indicated 5-6 years for *A. obscurus* in the UK, while Dobrovolsky (1970) indicated 5 years in the forest zone near Moscow, data that is supported by Regnier (1928) for France and Chrzanowski (1927) for Poland. For the life cycle of *A. ustulatus*, Toth (1984) suggested 5 years in Ukraine and 4 years for Southern Europe. Shorter cycles were indicated by Masler (1982) with 2-3 years, Furlan (1998) with 1-3 years and Hinkin (1983) with 2 years.

We cannot explain the missing increase of larval age observed during the third year under semi-natural conditions. Perhaps the sampling size (n = 19) was too low. Still, the duration of the life cycle of click beetles may also increase, if no food is available for longer periods during the development (Furlan, 1998).

Although the breadth especially the head width is suggested being a good criterion to determine instar stages (Ford, 1917), high variation in larval head width within one instar stage can complicate the identification of larval stages under field conditions. The mean values for head width of L1 of *A. obscurus* were lower in our study (0.20 mm) compared to data earlier published, i.e. 0.75 mm (Ford, 1917), 0.40 mm (Roberts, 1919) and 0.28 mm (Klausnitzer, 1994). Data for the head width of the present study are similar to Furlan (1998; 2004), where the average size of L1 larvae of *A. ustulatus* and *A. sordidus* was 0.19 mm and 0.18 mm respectively. In the current study, the body width measured for fully

grown larvae (1.46 mm) was slightly lower compared to 1.75-2.00 mm by Ford (1917) and Roberts (1921). The length measured for final instars in our study (22.03 mm) is in accordance to the length ranges (17-23 mm) and (22-26 mm) measured by Ford (1917) and Roberts (1921). Variations in the size within the same larval instar are likely due to species specific or phylogenetic differences within the same species.

In the present study, the average heat sum required for completing each larval instar of *A. obscurus* gradually increased with the age of the larvae. The final instar L11 took about eight times longer (1,587 DD) compared to L1 (190 DD). A similar gradual increase of the heat sum requirement was noted throughout the larval development of *A. ustulatus* and *A. sordidus* in Italy (Furlan 1998; 2004).

Under laboratory conditions at constant temperature (20 °C), the first pupa was discovered during the last week of May in the first year, while others were found in the month of August with completing their pupal period in about two weeks. Likewise, the pupation period of *Agriotes* species (*A. obscurus*, *A. lineatus* and *A. sputator*) observed by Salt and Hollick (1944) in the UK lasted from late June until the end of August. Similar observations on *A. obscurus* pupae were made by Horst (1922) and Subklew (1935) in Germany, Ford (1917) and Roberts (1919) in UK, Willaume (1924) in France and Chrzanowski (1927) in Poland.

Data gained in the study may help to develop new approaches for non-chemical wireworm control in organic production and implement IPM (Directive 2009/128/CE) in conventional cropping systems. Cultural control, such as by rotation design or soil tillage, is still the most suitable approach to cope with pest and disease problems in organic agriculture (Parker and Howard, 2001; Schepl and Paffrath, 2005). According to our findings, for site conditions as present in the Southern Rhineland the peak of oviposition of *A. obscurus* does occur in May. Intensive soil tillage during this period could therefore contribute to a decrease the larval population. The eggs hatch after three to four weeks and during the first year between 4 and 5 larval stages develop before winter rest. In the first year after oviposition, the larvae will undergo another 4-5 instars, resulting in a larval size, which already increases the risk of damage for sensitive crops, such as potato, lettuce, sugar beet and maize. For a minimum of three years prior to sensitive crop cultivation, rotation should be managed to grow no plant species favourable for oviposition and larval survival, i.e. crops that allow continuous soil cover (Furlan *et al*., 2009). In contrast, row crops such as faba bean, maize or field vegetables with longer periods of bare soil in spring are less attractive for oviposition and cause a higher larval mortality. Additionally, during the main period of oviposition, the soil will be repeatedly tilled and hoed (Furlan and Talon, 1997).The proposed adaptation in the crop rotation design to avoid potato damage by wireworms still require experimental evidence in the future.

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Authors' addresses: Daniel NEUHOFF (corresponding author: d.neuhoff@uni-bonn.de), Muhammad SUFYAN, Institute of Organic Agriculture, University of Bonn, Katzenburgweg 3, D-53115 Bonn, Germany; Lorenzo FURLAN, Veneto Agricoltura, viale dell'Università 14, 35020 Legnaro (PD), Italy.

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corrigenda

Larval development of *Agriotes obscurus* under laboratory and semi-natural conditions

Muhammad SUFYAN, Daniel NEUHOFF, Lorenzo FURLAN

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In table 2 (page 230) the headers of two columns have been mistakenly reversed.
"Head width" instead of "Average length"
"Average length" instead of "Head width"

Corrected table 2:

Table 2. Head width and body length of *A. obscurus* larvae examined over 2 years at constant temperature of 20 °C in vials. Means followed by different letters are significantly different, Tukey-Test (α = 0.05). Mortality rate (%) calculated from the number of remaining specimens from total for each instar.

Instars	Head width (mm)				Average length	No. of	Mortality rate
	Mean	SD	Max.	Min.	(mm)	specimens	(%)
L1	0.20 a	0.016	0.23	0.17	3.66	202	0
L2	0.27 b	0.023	0.33	0.23	4.60	132	35
L3	0.34 c	0.039	0.46	0.27	5.88	114	44
L4	0.43 d	0.061	0.62	0.32	8.00	105	48
L5	0.55 e	0.078	0.78	0.39	9.47	99	51
L6	0.70 f	0.103	1.00	0.45	11.80	96	52
L7	0.87 g	0.151	1.34	0.58	14.19	91	55
L8	1.05 h	0.156	1.45	0.71	17.43	91	55
L9	1.26 i	0.158	1.53	0.91	20.36	87	57
L10	1.37 j	0.158	1.63	1.06	19.95	85	58
L11	1.46 k	0.129	1.67	1.26	22.03	85	58