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Multi-baiting YATLORf sex pheromone traps to optimize click beetle (*Agriotes* spp., Coleoptera: Elateridae) monitoring for low-cost IPM of wireworms

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Abstract

Implementation of IPM in arable crops requires affordable monitoring tools. YATLORf traps baited with a synthetic pheromone lure for a target species have proven to be effective for monitoring Europe's most harmful soil pests: *Agriotes* spp. After the suitable lure position for each of the main *Agriotes* species was ascertained, different combinations of lures in the same trap were studied in various European countries. Trials were carried out between 2001 and 2007, with the traps being arranged in blocks. Each block contained one trap per treatment under study (i.e., traps baited with a single species lure and traps baited with combinations of two or more different species lures). Unlike most of the research outputs on sex pheromone lures (e.g., on Lepidoptera species), the results of this research have clearly shown that lures for many *Agriotes* species can be combined in the same trap without loss of performance against most species. Two clear exceptions were *A. sputator* and *A. rufipalpis*, which were sensitive to the presence of the geranyl octanoate in lures for other species. It was possible to multi-bait a trap, i.e., use up to four different lures (*A. brevis*, *A. sordidus*, *A. litigiosus,* and *A. ustulatus*) with good results, thus demonstrating for the first time that important soil pest species belonging to the same genus can be monitored with multi-baited sex pheromone traps. Multi-baiting the same trap resulted in significantly reduced monitoring costs.

Keywords *Agriotes brevis* · *A. ustulatus* · *A. sordidus* · *A. lineatus* · *A. sputator*

Introduction

Soil-insecticide use at planting is still a widespread prophylactic practice (Veres et al. 2020) despite causing a major impact on biodiversity worldwide (Pisa et al. 2017). The prophylactic approach is unjustified since populations exceeding thresholds do not often occur (Furlan et al. 2020; Labrie et al. 2020) and it goes against the principles of Integrated Pest Management (IPM), as described by Barzman et al. 2015.

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Tools such as pheromone traps can be very important for affordable risk assessment of soil pest damage so that farmers and IPM advisors can apply control solutions, including insecticides, only when and where they are needed, thus ensuring that the objectives of Directive 128/2009/EC of the European Parliament are met (Furlan et al. 2023).

Pheromone lures have been developed and optimized for all of the important click beetles of genus *Agriotes* (Coleoptera, Elateridae) in Europe (Furlan et al. 2001; Tóth et al. 2003), and suitable sex pheromone traps for monitoring them have become available (Furlan et al. 2001, 2020). Known as YATLORf (Yf) traps, they have proven to be an effective, low-cost tool for monitoring adults of the *Agriotes* spp., Europe's most important soil pests, as well as essential for IPM of the main arable crops (Furlan et al. 2001, 2020). Yf traps are designed to catch both mainly crawling and mainly flying click beetles, thus encompassing all *Agriotes* species with agricultural importance in Europe (Furlan et al. 2001); some of these species are important pests in North America, as well (Vernon et al. 2014a).

It became evident during the early phases of our long-term research that trap design and lure position were critical factors for catching different species of click beetle. We noted that in the early swarming period, beetles of a mainly crawling species (*A. brevis*) were caught only when lures were placed close to the soil in traps unsuitable for ground-level catches (Tóth et al. 2002b). This insight steered trap design toward a model that comprised different ways of catching the beetles and various slots for lure placement. Therefore, a vast number of field trials were conducted to ascertain the most effective trap-management solutions, including lure position in the trap and the effect of vegetation on capture potential (Furlan et al. 2023). The findings of this work led to reliable guidelines for trap use.

It has been found that combinations of lures in the same trap cannot generally be used to capture moths, as the pheromone component(s) of a given species often act as inhibitors, interfering with the pheromonal response of another closely (or not-so-closely) related species. One of the earliest examples was (*Z*)-8-dodecenyl acetate, the main pheromone component of the Oriental fruit moth (*Grapholita molesta* Busck, Lepidoptera: Tortricidae) (Arn et al. 1974), used in traps baited with (*E,E*)-8,10-dodecadien-1-ol, the main pheromone component of the codling moth (*Cydia pomonella* L, Lepidoptera: Tortricidae), leading to a slump in catches of the latter (Arn et al. 1974).

Consequently, this present study conducted extensive field trials to ascertain the most effective trap-management solutions, including a high number of combinations of pheromone lures for several important genus *Agriotes* click beetles. Trials exploited information on Yf trap management, particularly on the most suitable lure positions for catching a range of species. We aimed to determine which lure combinations did not have significant detrimental effects on any of the target species, meaning that multi-species trapping became feasible. Herein, we summarize the above trials, which were conducted in a number of European countries from 2001 to 2007.

Materials and methods

YATLORf (Yf) traps (Furlan and Gnes 2003) (Fig. 1) baited with pheromone lures are commonly employed to catch adult click beetles in Europe (Furlan et al. 2007). Our trials used pheromone lures from the CSALOMON® trap family (Plant Protection Institute, CAR, Budapest, Hungary). See earlier reports in the literature for the compositions of single lures (Table 1).

A range of sites in Italy, France, Germany, and Hungary were set up for field-trapping trials between 2001 and 2007 (Table 2) using agreed-upon trapping procedures (Roelofs and Cardé 1977; Furlan et al. 2023). The Yf trap's white bottom was placed face-down so that its brown edge was buried 1–2 cm beneath the surface. A standard seasonal schedule governed by each species' life cycle and behavior determined how the baits were managed. By way of example, *A. ustulatus* click beetles in northeast Italy swarm from early June to August, with *A. sordidus* beetles swarming from April to August, peaking in May, meaning that they swarm for much longer than *A. ustulatus*. *A. brevis* and *A. sordidus* share various swarming characteristics, but *A. brevis* swarms for longer, starting a little before *A. sordidus* (Furlan et al. 2007). All lures were replaced every 30 to 40 days when trial duration exceeded 1 month. The only exception was *A. brevis*, which was never replaced. Each time the traps were inspected, soil and any residue were dusted off the bottom. The insects were removed from the trap as follows: the trap was taken out of the ground and placed inside a large plastic bag; the trap was opened, dropping the insects into the bag; the trap was withdrawn and the bag was sealed immediately; the trap was then restored to its original position. All of the beetles were stored in cool conditions (5–8°C) so that their taxonomy could be recorded (Platia 1994).

The traps were set up in blocks. Each block had one trap per lure combination (treatment). Three to eight blocks were used in each trial. The traps were sited 8–10 m apart inside each block; blocks were located a minimum of 30 m apart. We inspected the traps at intervals of several days, mainly twice a week. On inspection captured insects were removed and recorded. The position of the trap was rotated clockwise within the block. The lures were put into three positions:

- Low: the vial was placed in the bottom slot (i.e., inside narrowest part of funnel) sealed and upside down (Fig. 1);
- Medium: the lure vial was placed in the middle slot between the white lids sealed and upside down (Fig. 1);
- High: the lure vial was placed in the top slot between the white lids sealed and upside down (Fig. 1).

For a more detailed description of lure positions, see Furlan et al. 2023.

A summary of the trials is reported in Table 2. Most of the possible lure combinations (treatments) in the same trap were compared with traps baited with a single lure. The combinations are summarized in Table 3. The aforementioned experimental procedure was implemented, with lure positions in the trap being chosen (e.g., the *A. brevis* lure in the low position) as per the results of Furlan et al. 2023.

Statistical analysis

All of the trials in this publication were set up as factorial trials to compare the number of beetles caught in Yf traps. Since the data available did not have Gaussian

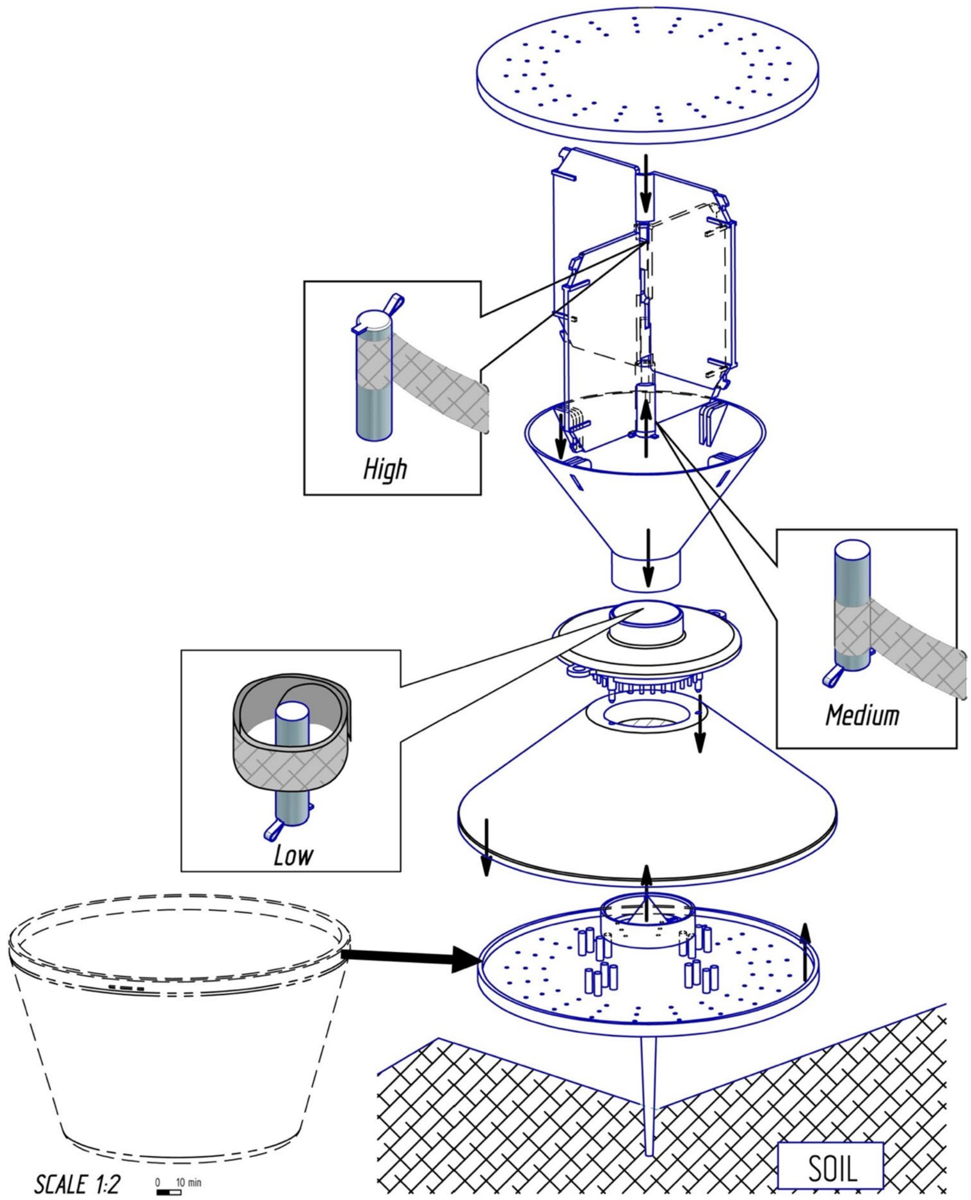

Fig. 1 Representation of lure positions in YATLORf traps. Figure reproduced from Furlan et al. 2023 under STM Permissions agreement

Table 1 Composition of click beetle pheromone lures used in the trials

Target species	Active ingredient(s)	References
Agriotes brevis Candeze	Geranyl butanoate + (*E,E*)-farnesyl butanoate 1:1	Tóth et al. (2002b)
Agriotes lineatus L.	Geranyl butanoate + geranyl octanoate 1:1	Tóth et al. (2003)
Agriotes litigiosus Rossi	Geranyl isovalerate	Tóth et al. (2003)
Agriotes obscurus L.	Geranyl hexanoate + geranyl octanoate 1:1	Tóth et al. (2003)
Agriotes proximus Schwarz	Geranyl butanoate + geranyl octanoate 1:1	Tóth et al. (2008)
Agriotes rufipalpis Brullé	Geranyl hexanoate	Tóth et al. (2002a)
Agriotes sordidus Illiger	Geranyl hexanoate	Tóth et al. (2002a)
Agriotes sputator L.	Geranyl butanoate	Tóth et al. (2003)
Agriotes ustulatus Schäller	(*E,E*)-farnesyl acetate	Tóth et al. (2003)

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Table 2 Main characteristics of trials for catching *Agriotes* click beetles with different lure combinations

Trial code	Site	Country	Year	Sparse/dense	Blocks	Inspections	Coordinates	*A. brevis*	Lure position	*A. sordidus*	Lure position	*A. litigiosus*	Lure position	*A. obscurus*	Lure position	*A. rufipalpis*	Lure position	*A. lineatus*	Lure position	*A. sputator*	Lure position	*A. ustulatus*	Lure position
1.	Hennef, Farm Wiesengut; Univ.Bonn	Germany	2004	S	3	9	50° 78′ 77″, 27° 70′ 42″							X	L			X	M	X	H		
2.	Hennef, Farm Wiesengut; Univ.Bonn	Germany	2004	D	3	5	50° 78′ 77″, 27° 71′ 00″							X	L			X	M	X	H		
3.	Debrecen, Látókép	Hungary	2004	S	4	22	47° 36′ 10″, 21° 35′ 52″							X	L			X	M	X	H		
4.	Campiello (Trento)	Italy	2006	S	3	8	46° 01′ 24″, 11° 34′ 98″							X	L			X	M			X	H
5.	Storo (Trento)	Italy	2006	S	3	13	45° 83′ 99″, 10° 55′ 86″					X	M	X	L								
6.	Villa Agnedo (Trento)	Italy	2006	S	3	5	46° 04′ 43″, 11° 54′ 16″	X	L					X	M								
7.	CEHM, Marsillagues	France	2004	S	4	23	43° 38′ 03″, 4° 10′ 10″			X	L							X	M				
8.	Greggio, Eraclea (Venice)	Italy	2001	D	5	11	45° 60′ 96″, 12° 66′ 45″	X	L	X	M												
9.	Greggio, Eraclea (Venice)	Italy	2003	D	4	2	45° 58′ 13″, 12° 70′ 23″	X	L	X	M												

Table 2 (continued)

Trial code	Site	Country	Year	Sparse/dense	Blocks	Inspections	Coordinates	*A. brevis*	Lure position	*A. sordidus*	Lure position	*A. litigiosus*	Lure position	*A. obscurus*	Lure position	*A. rufipalpis*	Lure position	*A. lineatus*	Lure position	*A. sputator*	Lure position	*A. ustulatus*	Lure position
10.	Crevalcore (Bologna)	Italy	2007	S	8	13	44° 45′ 20″, 11° 08′ 25″			X	L	X	M										
11.	Greggio, Eraclea (Venice)	Italy	2002	D	4	3	45° 60′ 85″, 12° 66′ 76″	X	L	X	M											X	H
12.	Zanazzo, Cessalto (Treviso)	Italy	2002	S	3	3	45° 41′ 57″, 12° 36′ 47″	X	L	X	M											X	H
13.	Eraclea (Venice)	Italy	2006	S	4	6	45° 60′ 85″, 12° 66′ 76″	X	L	X	M	X	H									X	H
14.	Greggio, Eraclea (Venice)	Italy	2006	S	4	13	45° 58′ 13″, 12° 70′ 23″					X	L									X	M
15.	Berton, Cavallino-Treporti (Venice)	Italy	2006	S	4	6	45° 46′ 45″, 12° 46′ 63″					X	L									X	M
16.	Hennef, Farm Wiesengut; Univ.Bonn	Germany	2004	D	4	1	50° 78′ 77″, 27° 72′ 42″	X	L			X	H	X	LM			X	LM	X	LM	X	H
17.	Hajdúböszörmény	Hungary	2005	S	4	9	47° 40′ 13″, 21° 31′ 15″							X	L	X	M	X	L				

S bare soil or sparse vegetation, *D* dense vegetation (see Furlan et al. 2023); *L* low lure position, *M* medium lure position, *H* high lure position (see M&M and Fig. 1)

S bare soil/sparse vegetation, *D* dense vegetation

Lure position (see M&M and Fig. 1): *L* low, *M* medium, *H* high

Table 3 Lure combinations: influence of a second lure, added to the target lure, on target species catches in field-trapping trials

Target species	Second lure added						
	A. brevis	*A. lineatus/A. proximus*	*A. litigiosus*	*A. obscurus*	*A. rufipalpis/A. sordidus*	*A. sputator*	*A. ustulatus*
A. brevis	XX	n.t.	T	T	T	T	T
A. lineatus	T	XX	T	T	n.t.	T	T
A. litigiosus	T	n.t.	XX	T	T	n.t.	T
A. obscurus	T	T	T	XX	T	T	T
A. rufipalpis	n.t.	T	n.t.	T	n.t.	n.t.	n.t.
A. sordidus	T	T	T	T	XX	n.t.	T
A. sputator	T	T	n.t.	T	n.t.	XX	n.t.
A. ustulatus	T	n.t.	T	n.t.	T	n.t.	XX

T tested combination, *n.t.* not tested, *XX* same lure composition

Table 4 Trial 1 Effect of adding *A. obscurus* and *A. lineatus* lures to an *A. sputator* lure on click beetle catches in Yf traps

Treatment	*A. lineatus*			*A. obscurus*			*A. sputator*		
	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. lineatus	19.5	a		0	c	– 100.0	0	b	– 100.0
A. lineatus + *A. obscurus* + *A. sputator*	42	a	115.38	3.5	b	– 83.7	1	b	– 96.7
A. obscurus	0.5	b	– 97.4	21.5	a		0	b	– 100.0
A. sputator	0	b	– 100.0	0	c	– 100.0	30	a	

Germany, sparse vegetation. Statistical analysis was conducted on the transformed data using the rank transformation. The letters indicate statistical differences determined by the Tukey HSD test ($p < 0.05$). The Diff. % column shows catch reduction or increase in any combination compared to the catch number in a single-baited trap

Table 5 Trial 2 Effect of adding *A. obscurus* and *A. lineatus* lures to an *A. sputator* lure on click beetle catches in Yf traps

Treatment	*A. lineatus*			*A. sputator*			*A. obscurus*		
	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. lineatus	2	a		0	b	– 100.0	0	ab	– 100.0
A. lineatus + *A. obscurus*	1	a	– 50.0	0	b	– 100.0	10	c	– 20.0
A. lineatus + *A. obscurus* + *A. sputator*	1.5	a	– 25.0	0	b	– 100.0	4	abc	– 68.0
A. obscurus	0	b	– 100.0	0	b	– 100.0	12.5	a	
A. sputator	0	b	– 100.0	10	a		0	bc	– 100.0

Germany, dense vegetation. For the statistical approach, see Table 4

Table 6 Trial 3 Effect of adding *A. obscurus* and *A. lineatus* lures to an *A. sputator* lure on click beetle catches in Yf traps

Treatment	*A. lineatus*			*A. sputator*		
	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. lineatus	1	a	0.00	0	b	– 100.0
A. lineatus + *A. obscurus* + *A. sputator*	1	a		0	b	– 100.0
A. sputator	0	b	– 100.0	3.5	a	

Hungary, sparse vegetation. For the statistical approach, see Table 4

Table 7 Trial 4 Effect of adding an *A. ustulatus* lure to a Yf trap baited with *A. obscurus* and *A. lineatus* lures on click beetle catches in Yf traps

	A. lineatus			*A. obscurus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. obscurus + *A. lineatus*	25	a		0.5	a	
A. obscurus + *A. lineatus* + *A. ustulatus*	13.5	a	– 46.0	0	b	– 100.0
A. ustulatus	0	b	– 100.0	0	b	– 100.0

For the statistical approach, see Table 4

Table 8 Trial 5 Effect of combining *A. obscurus* and *A. litigiosus* lures on click beetle catches in Yf traps

	A. obscurus			*A. litigiosus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. litigiosus	0	b	– 100.0	0	ns	–
A. obscurus	1.5	a		0	ns	–
A. obscurus + *A. litigiosus*	2	a	33.33	0	ns	–

The data are presented as Box-and-Whisker plots. To enhance the graphical representation, the values underwent a log(X + 1) transformation, which was performed solely for improved data visualization. For the statistical approach, see Table 4

Table 9 Trial 6 Effect of adding an *A. brevis* lure to a trap baited with an *A. obscurus* lure on click beetle catches in Yf traps

	A. obscurus			*A. brevis*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis	0	b	– 100.0	21.5	a	
A. obscurus	5	a		0	c	– 100.0
A. obscurus + *A. brevis*	7	a	40.00	4.5	b	– 79.1

For the statistical approach, see Table 4

Table 10 Trial 7 Effect of adding an *A. sordidus* lure to an *A. lineatus* lure on click beetle catches in Yf traps

	A. sordidus			*A. lineatus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. lineatus	0	b	– 100.0	0	ns	
A. lineatus + *A. sordidus*	2	a	100.00	0	ns	–
A. sordidus	1	a		0	ns	–

For the statistical approach, see Table 4

Table 11 Trial 8 Effect of combining *A. brevis* and *A. sordidus* lures on click beetle catches in Yf traps

	A. brevis			*A. sordidus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis	6.5	a		0	b	– 100.0
A. brevis + *A. sordidus*	9.5	a	46.15	0.5	a	0.00
A. sordidus	0	b	– 100.0	0.5	a	

For the statistical approach, see Table 4

distributions (verified with the Shapiro-Wilk test), the following procedure was performed: the data were analyzed with ANOVA after values had been transformed into ranks (Conover and Iman 1981; Noguchi et al. 2020). The separation of rank means was performed with the Tukey HSD test ($p < 0.05$). Data-processing was performed with

Table 12 Trial 9 Effect of combining *A. brevis* and *A. sordidus* lures on click beetle catches in Yf traps

	A. brevis			*A. sordidus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis	8.5	a		1	b	– 96.4
A. brevis + *A. sordidus*	7	a	– 17.6	18	a	– 34.5
A. sordidus	0	b	– 100.0	27.5	a	

For the statistical approach, see Table 4

Table 13 Trial 10 Effect of adding an *A. litigiosus* lure to a Yf trap baited with *A. sordidus* lures on catches of *A. sordidus* and *A. litigiosus* click beetles

	A. sordidus			*A. litigiosus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. litigiosus	0	b	– 100.0	5.5	a	
A. litigiosus + *A. sordidus*	0.5	a	0.00	6.5	a	18.18
A. sordidus	0.5	a		0	b	– 100.0

For the statistical approach, see Table 4

Table 14 Trial 11 Effect of adding an *A. ustulatus* lure to a Yf trap baited with *A. brevis* and *A. sordidus* lures on catches of *A. ustulatus* click beetles in Yf

	A. ustulatus			*A. sordidus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis + *A. sordidus*	0	b	– 100.0	0.5	ns	0.00
A. brevis + *A. sordidus* + *A. ustulatus*	4	a	– 20.0	0.5	ns	0.00
A. ustulatus	5	a		0	ns	– 100.0

For the statistical approach, see Table 4

Table 15 Trial 12 Effect of adding an *A. ustulatus* lure to a Yf trap baited with *A. brevis* and *A. sordidus* lures on catches of *A. ustulatus* click beetles in Yf

	A. sordidus			*A. ustulatus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis + *A. sordidus*	0	a		0	b	– 100.0
A. brevis + *A. sordidus* + *A. ustulatus*	0	a	ns	20	a	– 20.0
A. ustulatus	0	b	ns	25	a	

For the statistical approach, see Table 4

Table 16 Trial 13 Effect of adding *A. ustulatus* and *A. litigiosus* lures to a Yf trap baited with *A. brevis* and *A. sordidus* lures on catches of *A. litigiosus* and *A. ustulatus* click beetles

	A. litigiosus			*A. ustulatus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. brevis + *A. sordidus*	0	b	– 100.0	0	c	– 100.0
A. brevis + *A. sordidus* + *A. litigiosus* + *A. ustulatus*	28	a	– 5.1	15.5	a	14.81
A. litigiosus	29.5	a		0	c	– 100.0
A. ustulatus	0	b	– 100.0	13.5	a	

For the statistical approach, see Table 4

Table 17 Trial 14 Effect of combining *A. litigiosus* and *A. ustulatus* lures on click beetle catches in Yf traps

	A. litigiosus			*A. ustulatus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. litigiosus	0.5	a		0	b	– 100.0
A. litigiosus + *A. ustulatus*	0.5	a	0.00	7	a	– 54.8
A. ustulatus	0	b	– 100.0	15.5	a	

For the statistical approach, see Table 4

Table 18 Trial 15 Effect of combining *A. litigiosus* and *A. ustulatus* lures on click beetle catches in Yf traps

	A. litigiosus			*A. ustulatus*		
Treatment	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. litigiosus	10	a		0	ns	–
A. litigiosus + *A. ustulatus*	12.5	a	25.00	0	ns	–
A. ustulatus	0	b	– 100.0	0	ns	–

For the statistical approach, see Table 4

STATGRAPHICS 19®. The tables display all of the data as medians of the sampled values (no. of beetles caught by the trap).

Results

Each trial was analyzed independently, with each table referring to the trial code in Table 2, which details the trial characteristics. Tables 4, 5, 6 report results for the main interactions between *A. obscurus, A. lineatus*, and *A. sputator*, three species that can be found at the same site (Furlan et al. 2007). The presence of an *A. sputator* lure did not influence the capture potential of Yf traps single-baited with an *A. lineatus* lure, but it did significantly reduce *A. obscurus* catches when compared to single-baited traps. Catches of *A. sputator* beetles were almost completely inhibited at all trial sites when *A. lineatus* and *A. obscurus* lures were used in the same trap.

Table 7 reports the effect of *A. ustulatus* lures in Yf traps baited with both *A. obscurus* and *A. lineatus* lures. The presence of *A. ustulatus* lures did not influence *A. lineatus* catches but it did deplete *A. obscurus* catches. Table 8 reports the effect on *A. obscurus* catches when an *A. litigiosus* lure was added; no impact on *A. obscurus* beetle catches was observed. Likewise, an additional *A. brevis* lure had no impact on *A. obscurus* beetle catches. Catches of *A. brevis,* however, were significantly reduced by the presence of an *A. obscurus* lure (Table 9). Catches of *A. sordidus* were not influenced by the presence of an *A. lineatus* lure in the same trap (Table 10). *A. brevis* and *A. sordidus* can be found with *A. litigiosus* and/or *A. ustulatus* at the same site (Furlan et al. 2007).

Tables 11 and 12 show that there was no impact on beetle catches when *A. brevis* and *A. sordidus* lures were combined in the same trap; likewise, a combination of *A. sordidus* and *A. litigiosus* lures showed no interference (Table 13).

The presence of *A. ustulatus* and *A. litigiosus* lures, single or combined, alongside *A. brevis* and *A. sordidus* lures already in the same Yf trap, had no impact on catches of *A. ustulatus* (Tables 14 and 15) or *A. litigiosus* beetles (Table 16), meaning that *A. ustulatus* and/or *A. litigiosus* catches were not impacted by *A. brevis* and *A. sordidus* lures. Table 17 (high *A. ustulatus* population) and Table 18 (high *A. litigiosus* population) confirm that *A. ustulatus* and *A. litigiosus* lures did not interact negatively.

Table 19 shows the results of monitoring *A. lineatus* when lures were placed in the Yf trap to monitor other target species. The *A. brevis* and *A. obscurus* lures, which contain the same active ingredients as the *A. lineatus* lure (geranyl butanoate and geranyl octanoate respectively) caught as many *A. lineatus* beetles as the specific *A. lineatus* lure. The presence of an *A. ustulatus* lure had no impact. The trial also confirmed that catches of *A. sputator* in the same Yf trap were inhibited when the other lures contained geranyl octanoate. Table 20 shows that catches of *A. rufipalpis* were also inhibited when lures containing geranyl butanoate (contained for example in *A. lineatus* lures) were used in the same Yf trap.

Discussion

Table 21 shows results of pairwise comparisons when a second lure was added to the same trap alongside the target species lure. In most cases, there was no significant

Table 19 Trial 16 Evaluation of whether *A. lineatus* and *A. obscurus* can be monitored when their specific lures are replaced with ones for other species containing an active ingredient in *A. lineatus* lures

Species lure	Compounds			*A. lineatus*			*A. sputator*			*A. obscurus*		
	Species 1	Species 2	Species 3	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. sputator	Geranyl butanoate			0	b	− 100.0	45	a		1	bc	− 95.3
A. lineatus	Geranyl butanoate + geranyl octanoate 1:1			19.5	a		0	b	− 100.0	0	c	− 100.0
A. obscurus	Geranyl hexanoate + geranyl octanoate 1:1			0	b	− 100.0	0	b	− 100.0	21.5	a	
A. brevis + *A. obscurus* + *A. ustulatus*	Geranyl butanoate + (E,E)-farnesyl butanoate	Geranyl hexanoate + geranyl octanoate 1:1	(E,E)-farnesyl acetate	28.5	a	46.15	0	b	− 100.0	15.5	ab	− 27.9
A. lineatus + *A. sputator* + *A. litigiosus*	Geranyl butanoate + geranyl octanoate 1:1	Geranyl butanoate	Geranyl isovalerate	35	a	79.49	0.5	b	− 98.9	4	abc	− 81.4

The values reported are the median of the samples, and the letters refer to the statistical differences using the Tukey HSD test ($p < 0.05$) on the transformed data using the rank transformation. The comparison was conducted within the columns

influence, but when the *A. lineatus* or *A. obscurus* lures were added to the *A. sputator* lure, catches of *A. sputator* plummeted. Likewise, when the *A. lineatus* lure was added to traps containing the *A. rufipalpis* lure, catches of *A. rufipalpis* also decreased significantly. It was also demonstrated that *A. litigiosus* and *A. ustulatus* lures could be added as third and fourth lures to traps already baited with *A. brevis* and *A. sordidus* lures without any negative impact on the number of catches by single lures (Table 16).

The addition of *A. litigiosus* and/or *A. ustulatus* lures to traps baited with *A. sordidus* and/or *A. brevis* lures did not reduce the catches of any of the species, provided that each lure was placed into its correct trap position: *A. brevis* in the low position; *A. sordidus* in the medium position; *A. litigiosus* and *A. ustulatus* in the medium and/or high positions (Furlan et al. 2023). This way it was possible to bait the same trap with up to four different lures, with optimal results for each of the target species.

It is clear from the results that lures for many *Agriotes* species can be combined without loss of performance against most species. The only clear exceptions were *A. sputator* and *A. rufipalpis* (both sensitive to the addition of other lures containing geranyl octanoate); and *A. brevis* (sensitive to the addition of the *A. obscurus* lure, which also contains geranyl butanoate). In bare soil or sparse vegetation, *A. brevis* and *A. lineatus* require the lure to be in the same trap position (i.e., low), meaning that in practical terms it would be better to use two separate traps when both species are important. Individual traps are also advisable when the target species (e.g., *A. brevis* and *A. sputator*) share a pheromone component (Table 1 and 21). This prevents any interference between lures and the need to separate similar beetles when counting the total for each species.

The inhibitory effect on *A. sputator* catches can probably be attributed to geranyl octanoate, which is used in both the *A. lineatus* and *A. obscurus* lures. No other lures contained this compound. Likewise, as geranyl octanoate is contained in lures for other species, catches of *A. rufipalpis* decreased significantly when lures containing it were added to traps.

In North America-based studies, the presence of geranyl hexanoate (pheromone component of *A. mancus* Say) also inhibited *A. sputator* catches (Singleton et al. 2023), suggesting that *A. sputator* is more sensitive to the components of additional lures than other *Agriotes* spp.

Using *A. sputator* and *A. obscurus* lures in the same trap enables *A. lineatus* to be caught as well, since *A. obscurus* lures contain geranyl octanoate and *A. sputator* lures contain geranyl butanoate. Both act as *A. lineatus* attractants, and the second main component in *A. obscurus* lures, geranyl hexanoate, does not inhibit *A. lineatus*.

No data have been presented on the addition of a second lure when *A. proximus* was the target species. High

Table 20 Trial 17 Effect of adding geranyl butanoate (in *A. lineatus* and *A. obscurus* lures) to geranyl hexanoate (only compound in *A. rufipalpis/A. sordidus* lures) on catches of *A. rufipalpis* click beetles in Yf traps

Species lures	Compounds		*A. lineatus*			*A. rufipalpis*		
	Species 1	Species 2	Median	Sign	Diff. (%)	Median	Sign	Diff. (%)
A. lineatus	Geranyl butanoate + geranyl octanoate 1:1		1	a		0	b	− 100.0
A. rufipalpis	Geranyl hexanoate		0	c	− 100.0	2.5	a	
A. lineatus + *A. obscurus*	Geranyl butanoate + geranyl octanoate 1:1	Geranyl hexanoate + geranyl octanoate 1:1	0.5	b	− 50.0	0	b	− 100.0

The values reported are the median of the samples, and the letters refer to the statistical differences using the Tukey HSD test ($p < 0.05$) on the transformed data using the rank transformation. The comparison was made within the columns

Table 21 Influence of a second lure, added to the target lure, on target species catches in field-trapping trials

Target species	Second lure added						
	A. brevis	*A. lineatus/A. proximus*	*A. litigiosus*	*A. obscurus*	*A. rufipalpis/A. sordidus*	*A. sputator*	*A. ustulatus*
A. brevis	XX	n.t.	OK	Partial INH	OK	X	OK
A. lineatus	OK	XX	OK	OK*	n.t.	OK	OK
A. litigiosus	OK	n.t.	XX	OK	OK	n.t.	OK
A. obscurus	OK	OK	OK	XX	X	OK	OK
A. rufipalpis	n.t.	INH	n.t.	INH	XX	n.t.	n.t.
A. sordidus	OK	OK	OK	X	XX	n.t.	OK
A. sputator	X	INH	n.t.	INH	n.t.	XX	n.t.
A. ustulatus	OK	n.t.	OK	n.t.	OK	n.t.	XX

OK no significant influence, *INH* catches of target significantly reduced ($p < 0.05$), *n.t.* not tested, *XX* same lure composition, *X* one a.i. in common

*a catch reduction in one trial

numbers of *A. proximus* were only caught in Portugal, with lower numbers being caught in Bulgaria at one site in earlier Europe-wide trappings (Furlan et al. 2007). Furthermore, we were unable to conduct trials specifically targeting *A. proximus* over the course of the present trials. As *A. proximus* has proven to be similar to *A. lineatus* (Tóth et al. 2008) in all other aspects of its pheromone composition, we have reason to believe that the two species are also similar with regard to the effect of lure position and additional lures in the same trap.

In light of the interaction between lures and the effect of lure position, the most effective lure combinations in Yf traps are summarized in Table 21. In practical terms, some combinations proved to be useless, as the two species were not usually important at one site and in the same period of the season simultaneously.

Also note that the findings of this study obtained on European populations should not be automatically applied to populations on other continents. For example, Canada-based studies showed that the addition of the *A. lineatus* lure to traps with the *A. obscurus* lure vastly reduced catches of *A. obscurus* when it was the target species (Vernon et al. 2014b; van Herk et al. 2022). The authors state that *A. lineatus* do not enter an *A. obscurus* trap if they have a choice. This discrepancy between the Canada-based studies and the present paper may have been caused by the former using a trap with a vastly different design to the YATLORf traps. Alternatively, the two species, which were introduced to North America from Europe, might have acquired new evolutionary traits in their newly invaded geographical area. In the present study, the combination of *A. obscurus* and *A. lineatus* lures were tested in Germany, Hungary and Italy, with no interference being found in any country. No trials were conducted in the UK, where it is highly probable that the Canada click beetles came from. Therefore, we conclude that Yf traps can be multi-baited with *A. obscurus* and *A. lineatus* lures on mainland Europe.

The pheromone lures for *Agriotes* spp. discussed in the present study are remarkably different from the pheromone lures for moths. It is most rare that lures for two moth species of the same genus can be combined in the same trap without inhibitory effects. However, the present paper demonstrates that this can be done without any issues for most of the click beetles studied. One possible explanation is that competition for a species-specific pheromonal communication channel is more intense in moths, where a compound can be found in the pheromone of dozens of species (or more) (Roelofs and Cardé 1977), thus making the role of secondary pheromone compounds more important. The results of our study suggest that competition for a selective communication channel might not be so intense in *Agriotes* click beetles. This notion is also indirectly supported by the relatively few "side catches" by the lures used in earlier trials conducted at numerous sites across Europe (Furlan et al. 2007).

A recent North America paper reports that the pheromones of some *Agriotes* spp. (non-native to North America but introduced by human activities) can be combined with pheromones of *Limonius* spp., which is indigenous to North America (Lemke et al. 2023). This may support indirect evidence that multi-baiting pheromone traps could work when the target species did not evolve in that geographical area, opening up the opportunity of adding pheromones of heterogenic click beetles to the same trap in a bid to monitor multiple elaterid pests. However, as Lemke et al. (2023) correctly comment, such mixed lures should be specifically evaluated for each species combination.

Conclusions

Sex pheromone traps have become an important tool for monitoring wireworms belonging to genus *Agriotes* (Furlan et al. 2020), as well as for monitoring other genera, e.g., *Limonius* (Lemke et al. 2023) and *Melanotus* (Schoeppner et al. 2023). However, their use must be optimized if they are to make a tangible contribution to IPM. In our research, multi-baiting the same trap, i.e., using several lures, enabled various species to be caught in one trap. It was possible to multi-bait a trap with up to four different lures (*A. brevis, A. sordidus, A. litigiosus,* and *A. ustulatus)* with good results, thus demonstrating for the first time that important soil pest species belonging to the same genus can be monitored with multi-baited sex pheromone traps.

Brief guidelines for optimum use of Yf traps (compiles the results of Furlan et al. 2023 and those included in this paper):

1. The most reliable way to assess beetle population pressure when the target field is covered with dense vegetation is to position the trap just outside the target field, or in a nearby field, i.e., within about 200 m, with bare soil or sparse vegetation. Target fields with bare soil or sparse vegetation have no restrictions, thus the best position is inside the target field. The only exception is *A. brevis* traps, which must always be placed in the target field (Furlan et al. 2023);
2. Traps may be multi-baited in accordance with conditions in the monitored area. Possible combinations are listed in Table 21. The addition of *A. litigiosus* and/or *A. ustulatus* lures to traps initially baited, or still baited with *A. sordidus* and/or *A. brevis* lures did not reduce the catches of any species provided that each specific lure was placed into its correct trap position: *A. brevis* in the low position; *A. sordidus* in the medium position; *A. litigiosus* in the high position; and *A. ustulatus* in the medium position (Fig. 1);
3. In both single and multi-baited traps, *A. brevis* and *A. lineatus* lures need to be placed in the low position when the field has bare soil or sparse vegetation cover. The high position is less suitable for *A. brevis, A. obscurus,* and *A. lineatus* when the field has bare soil or sparse vegetation cover. There are no restrictions for the other species, i.e., any position is suitable.

Multi-baited traps can significantly reduce monitoring costs in terms of materials, as one trap baited with four lures saves the cost of three Yf traps. In addition, major savings are made in terms of the time and travel needed for trap inspections. One downside is that they require more time for beetle identification and counting, as the captured species need to be separated. The results of this study suggest that competition for a selective communication channel might not be very intense in *Agriotes* click beetles.

This research enables Yf traps to be exploited to their fullest potential, resulting in easier, more affordable Integrated Pest Management (IPM) of soil pests, such as wireworms. Consequently, farmers can establish which areas and fields have pest populations below the economic threshold (Furlan et al. 2020) and implement IPM in accordance with Directive 128/2009/EC.

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