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PRELIMINARY RESULTS REGARDING INTEGRATED PEST MANAGEMENT METHODS OF ARTHROPOD SPECIES IN SWEET POTATO CROP – CASE STUDY – WIREWORMS

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Abstract

Wireworms, larvae of click beetles, Agriotes spp, are important pests of sweet potato. There is currently no curative treatment available to control wireworms and preventive treatments are mainly chemical. Therefore, is a need for a better understanding of the damaging factors to develop effective integrated control strategies and methods (IPM). This study aims to present the preliminary results on bait and pheromone traps used in a sweet potato crop to evaluate the densities of three major wireworm species in south-eastern Europe (Agriotes lineatus, A. obscurus, and A. ustulatus). Biological control with Metharizium anisopliae and Beauveria bassiana was applied. Agriotes ustulatus was the main species caught with pheromone traps, over 2400 specimens, while A. lineatus were 270 specimens, and A. obscurus 280. Statistical analysis was performed for evaluating the effectiveness of biological control with Metharizium anisopliae and Beauveria bassiana, the result demonstrating the viability of the method, the number and size of commercial sweet potatoes being significantly higher in the treated plot. The study offers perspectives to develop preventive and curative solutions for the sustainable control of wireworms.

Key words: *IPM, biological control, bait traps, pheromone traps.*

INTRODUCTION

The model of conventional agriculture involving the use of pesticides is questioned in terms of sustainability, environmental and human health (Wilson and Tisdell 2001; Tilman et al., 2002; Geiger et al., 2010). One of the biggest challenges for agriculture in the coming years will be to reconcile productivity with other components of sustainability, especially in order to achieve substantial reductions in pesticide use (Foley et al., 2011; Lechenet et al., 2014).
European Directive 128/2009/EC on the sustainable use of pesticides has made it mandatory to apply the principles of integrated pest management (IPM) in the European Union from 1 January 2014 (Barzman et al., 2015).
The first IPM principle recommends the prevention and suppression of pests by adopting crop rotation and other preventive agronomic strategies that can reduce the risk of pests and the need for plant protection measures. Therefore, in order to comply with Directive 128/2009/EC, farmers should make the most of agronomic solutions and research should support them in developing the best strategies (Furlan et al., 2020).
Particularly challenging is the control of soil-dwelling-pests because they are difficult to access. Even though these insects are mostly ‘‘out of sight’’ their feeding pressure on belowground parts of crops is of great economic importance (Hunter, 2001; Blossey and Hunt-Joshi 2003; Blackshaw and Kerry, 2008).
Elateridae, popularly known as click beetles, is a family of beetles that is distributed worldwide and includes about 9,000 species (Barsics et al., 2013).
The family includes 27 genera, but most of the significant arable crop pests belong to the genus *Agriotes*.
Agriotes are found mainly in the Holarctic and eastern areas and there are about 200 species worldwide.
Click beetles are characterized by a multi-annual life cycle, which differs dramatically between species. They can be divided into two

main groups. The first group consists of species with adults that do not overwinter, live a short period and lay eggs a few days after mating (*A. ustulatus, A. litigiosus*), (Furlan, October, 2004).
The second brings together species with adults that overwinter and live for months. They lay eggs for a longer period (*A. sordidus, A. brevis, A. lineatus, A. sputator, A. obscurus, A. rufipalpis* and *A. proximus*).
Adults emerge from the soil in the spring, usually from late March to early May. Females *A. obscurus* L., *A. sputator* L. *and A. sordidus lay* their eggs in May or June, below the soil surface (Miles 1942; Furlan, 2004) while the oviposition peak of *A. ustulatus* occurs in July and early August (Furlan, 1996).
The larvae of *Agriotes* spp. are popularly called "wireworms" due to their elongated body, covered by a strong chitinized, yellow-brown skin. In the last stage of development, the body can reach a length of 18-30 mm. It has 3 pairs of well-developed legs and mandibles.
Polyphagous pests, with the help of strong mandibles, dig into the tubers leaving small, round holes on the surface and narrow tunnels inside the tuber.
Although the attack does not affect the yield, it causes a considerable decrease in quality, which can make the tubers unmarketable even when the damage is relatively small.
In the specialized literature, various authors have conducted studies on methods of monitoring and integrated pest management of wireworms. The most relevant are listed in Table 1.

Table 1. Agriotes studies review

Reference	Study subject	Species/crop type
Furlan and Howard, 2021	Capturing distance of YATLOR pheromone traps for clic beetles *Agriotes (A. brevis, A. sordidus, A. litigiosus* and *A. ustulatus).* Male adults were released into the open field where the rate and distance at which they were recaptured were tracked. Catch rate was significantly affected by distance, species and wind direction and decreased as the distance increased. Most beetles were caught at short distances (up to10 m), in the first five days	Corn, soybeans, sugar beet, wheat, black field.
Furlan et al., 2001	Evaluation of the efficiency of YATLOR and VAR pheromone traps for *A. brevis, A. obscurus, A. lineatus, A. sputator, A. rufipalpis, A. litigiosus* and *A. ustulatus.* Investigating the relationship between catches in pheromone traps and the level of wireworm soil population	Soybeans, cereals
Furlan et al., 2020	The potential of a simple agronomic strategy, namely the proper timing of meadow ploughing to prevent wireworm attacks on maize and other arable crops in early stages	Corn, fodder plants
Staudacher et al., 2013	Reducing wireworm damage on corn plants by diversifying crops	Corn, wheat, legumes
Parker et al., 2001	Monitoring methods and agronomic methods applied to reduce the number of soil wireworms larvae Biological control methods The insecticidal effect of glucosinolates	Potatoes
Barsics et al., 2013	Identification of Agriotes species, life cycle description, optimal times for control measures application Correlation between the risk of attack with the number of wireworms caught in bait traps The advantage of using pheromone traps for monitoring but also in control Agrophytotechnical methods Biofumigation control with glucosinolates Biological control methods	
Furlan, 2007	Accurate monitoring of Agriotes species. Prediction of the degree of attack Agrofytotechnical control methods: crop rotation, synchronization of different tillage techniques depending on the ecology of the target *Agriotes* species, irrigation synchronization Biological control methods	
Parker, 1996	Monitoring methods for wireworms using cereal bait traps	Potatoes
Furlan, 1998	*Agriotes ustulatus* biology. Larval development, pupation, life cycle and practical implications.	

Vernon and van Herk, 2013	The importance of identifying the *Agriotes* species present in the crop. Methods of identification of *Agriotes* species. Biology and ecology of harmful *Agriotes* species. Description of the activity of harmful *Agriotes* larvae. Methods for monitoring *Agriotes* species and risk assessment in potato cultivation. Control methods: agronomic methods, biological methods, biotechnical methods.	Potatoes
MacKenzie, 2010	Agrophytotechnical methods for controlling wireworms (crop rotations, push-pull strategy, immobilization strategy)	Carrots, alfalfa, mustard, oats, buckwheat, barley, clover, flax, wheat.
Morales-Rodriguez et al., 2017	Monitoring methods of *Agriotes* larvae using 4 types of bait traps	Cereals
Furlan, 2014	Economic damage thresholds (correlations between the number of larvae belonging to different *Agriotes* species caught by different methods and the degree and intensity of the attack on maize plants)	Maize
Furlan et al., 2010	The role of biofumigation in wireworm control.	
Poggi et al., 2018	The influence of climatic factors, agronomic practices, identification of dominant *Agriotes* species and landscape characteristics in assessing the risk of wireworm attack.	Maize
Saussure et al., 2015	Management of damage caused by wireworms in corn crops using landscape-scale strategies.	Maize

MATERIALS AND METHODS

Integrated pest management

Integrated pest management is a systems approach to pest control that combines biological, cultural, and other alternatives to chemical control with the judicious use of pesticides. The objective of IPM is to maintain pest levels below economically damaging levels while minimizing the harmful effects of pest control on human health and environmental resources.

In 2021, a field experiment was established on a one-hectare organic sweet potato crop (*Ipomoea batatas*) in (Călărași county, southeast Romania) that harbored high densities of *Agriotes* larvae.

Agronomic methods

Economically these methods are the cheapest control methods. It prevents pest multiplication and attack. Significantly reduce the number of treatments required and it is used for long periods and in large areas.

In organic vegetal farms, biodiversity is a key factor for sustainable production. (Toncea, 2016).

Due to the multi-annual biological cycle of wireworms (Furlan, 2004; Parker and Howard, 2001), crop rotation is considered good agricultural practice for pest control, when it includes plant species that do not host *Agriotes*.

Diversity in plant cultivation is achieved through a combination of various and relatively long crop rotations (Table 2).

Table 2. Crop rotation used on the experimental field

Plot/ year	2021	2022	2023	2024	2025	2026	2027
1	Alfa-alfa	Alfa-alfa	Egg-plant	Peas– Oats/ Bro-ccoli	Sweet potato	Courgette	Alfa-alfa
2	Alfa-alfa	Alfa-alfa	Alfa-alfa	Egg-plant	Peas – Oats/ Bro-ccoli	Sweet potato	Courgette
3	Courgette	Egg-plant	Peas– Oats/ Bro-ccoli	Sweet potato	Courgette	Alfa-alfa	Alfa-alfa
4	Eggplant	Peas– Oats/ Bro-ccoli	Sweet potato	Courgette	Eggplant	Peas–Oats/ Bro-ccoli	Sweet potato
5	Peas– Oats/ Bro-ccoli	Sweet potato	Courgette	Alfa-alfa	Alfa-alfa	Alfa-alfa	Egg-plant
6	Sweet potato	Courgette	Alfa-alfa	Alfa-alfa	Alfa-alfa	Egg-plant	Peas–Oats/ Bro-ccoli

Tillage, sweet potato crop varieties used and planting time

The larvae migrate vertically through the soil depending on the interaction between the climate conditions and the soil texture. In Europe, they generally migrate twice a year, in spring and autumn, when there are abiotic favorable conditions in the upper layers of the soil (Jung et al., 2012; Parker and Howard, 2001), making them vulnerable to tillage during this period. Tillage and manual hoeing reduce the number of eggs and young larvae by mechanical damage. It brings them to the surface of the soil, where they are exposed to predation and desiccation (Table 3).

Table 3. Tillage practices used on the experimental field in 2021

Tillage date	Equipment used
15/03	Rotary tiller
29/03	Rotary tiller
26/04	Rotary tiller
17/05	Rotary tiller
07/06	Rotary tiller
25/06	Hoe (manual)

The varieties ROK1 and KSC Korea, are resistant to abiotic and biotic stress (developed by The Research and Development Station for Plant Culture on Dăbuleni Sands).

Respecting the optimal planting time (May 15-20) significantly reduces the attack of Agriotes larvae. On the experimental plot, the planting took place on May 25.

The delay of planting by 15-30 days causes massive decreases in tuber production and increases the degree of wireworms attack.

Wireworms generally have two intense periods of activity that can result in significant damage to the crop. Intense periods of activity occur from March to May and from September to October. Any delay in harvesting the crop brings an additional risk of damage to the tubers.

Physical-Mechanical methods

Bait traps

The basic principles of an integrated pest management program include pest identification through monitoring (Barzman et al., 2015).

Worm larvae are attracted to CO_2-producing sources, such as germinating seeds, plant respiration, and decaying plant material. From the large number of CO_2-producing baits tested, including fruit and vegetables (eg melons, carrots and potatoes), processed cereals (eg bran, oats and flour), germinated cereal seeds (eg wheat, barley) and/or other seeds (eg corn, sorghum) have been found to be most effective.

Bait traps made and used in accordance with (Parker, 1996) were deployed to estimate wireworm population densities from April to mid-May. The bait traps were placed on April 12, when the soil temperature (5 cm deep) exceeded 7^0 C.

On May 12, the baits were removed from the soil, on average, 3 larvae of wireworms were caught per trap which presents a high risk of economic damage.

Biotechnical methods

Pheromone traps are used for monitoring, but in large numbers, they can be useful in controlling pests by mass capture of adults.

Pheromone traps for *Agriotes ustulatus, Agriotes lineatus, Agriotes obscurus* males were purchased from the Csalomon Plant Protection Institute in Hungary and were randomly placed in the sweet potato crop.

The main characteristics of application of pheromone traps were as follows:

Table 4. Number of Pheromone traps and disposal time

Disposal time	Pheromone species	Number of pheromone traps
28/06	*A. ustulatus*	4
28/06	*A. lineatus*	2
28/06	*A. obscursus*	2

Biological methods

It involves the use of living organisms and the products of their biological activity in order to regulate pest populations.

Fungal preparations are holistic tools in sustainable agriculture.

Fungal preparations with enzyme extract from *Beauveria bassiana* and *Metarhizium anisopliae* (BMV certified organic product) were applied by drip on 12 rows 750 meters long and 1 row was left untreated to verify the efficiency of the biological treatment (Table 5).

Table 5. Method and application time of the biological treatment

Application time	Liters/hectare	Method of application
20/07	3	Drip system
26/07	3	Drip system
02/08	3	Drip system
09/08	3	Drip system
17/08	3	Drip system
26/08	3	Drip system

RESULTS AND DISCUSSIONS

The first step in wireworm management consists in assessing the risk of crop damage by monitoring the level of populations in place (Barsics et al., 2013). The day after the pheromones traps were installed an inspection was made (Table 6). The pheromones were changed after 30 days.

Table 6. Monitoring results after one day of the pheromone traps disposal

Time of inspection	Species/trap number	Male adults captured
29/06	*A ustulatus* 1	62
29/06	*A ustulatus* 2	55
29/06	*A ustulatus* 3	58
29/06	*A ustulatus* 4	61
29/06	*A lineatus* 1	8
29/06	*A lineatus* 2	12
29/06	*A obscurus* 1	9
29/06	*A obscurus* 2	8

The inspections were made at the following intervals by Table 7:

Table 7. Pheromone traps monitoring results

Time of inspection	Species/trap number	Male adults captured	Average caught/day
07/07	*A ustulatus 1*	490	61.25
07/07	*A ustulatus 2*	487	60.88
07/07	*A ustulatus 3*	468	58.50
07/07	*A ustulatus 4*	502	62.75
07/07	*A lineatus 1*	70	8.75
07/07	*A lineatus 2*	90	11.25
07/07	*A obscurus 1*	84	10.50
07/07	*A obscurus 2*	77	9.63
21/07	*A ustulatus 1*	862	61.57
21/07	*A ustulatus 2*	886	63.29
21/07	*A ustulatus 3*	863	61.64
21/07	*A ustulatus 4*	902	64.43
21/07	*A lineatus 1*	114	8.14
21/07	*A lineatus 2*	138	9.86
21/07	*A obscurus 1*	118	8.43
21/07	*A obscurus 2*	122	8.71
04/08	*A ustulatus 1*	643	45.93
04/08	*A ustulatus 2*	628	44.86
04/08	*A ustulatus 3*	682	48.71
04/08	*A ustulatus 4*	614	43.86
04/08	*A lineatus 1*	67	4.79
04/08	*A lineatus 2*	72	5.14
04/08	*A obscurus 1*	68	4.86
04/08	*A obscurus 2*	74	5.29
18/08	*A ustulatus 1*	402	28.71
18/08	*A ustulatus 2*	388	27.71
18/08	*A ustulatus 3*	396	28.29
18/08	*A ustulatus 4*	404	28.86
18/08	*A lineatus 1*	22	1.57
18/08	*A lineatus 2*	21	1.50
18/08	*A obscurus 1*	26	1.86
18/08	*A obscurus 2*	23	1.64
20/08	*A ustulatus 1*	1	0.5
20/08	*A ustulatus 2*	1	0.5
20/08	*A ustulatus 3*	1	0.5
20/08	*A ustulatus 4*	2	1
20/08	*A lineatus 1*	0	0
20/08	*A lineatus 2*	0	0
20/08	*A obscurus 1*	0	0
20/08	*A obscurus 2*	0	0

The final monitoring results of *Agriotes* adults caught were as follows:

Table 8. Final monitoring results and economic thresholds

Agriotes Species	Adults caught	Economic threshold
A ustulatus 1	2420	300
A ustulatus 2	2434	300
A ustulatus 3	2455	300
A ustulatus 4	2485	300
A lineatus 1	222	200
A lineatus 2	315	200
A obscurus 1	280	200
A obscurus 2	291	200

The monitoring, of the 3 major *Agriotes* species present in the field, between 28 of June and 20 of august shows that the economic threshold of 300 *A. ustulatus* adults caught per trap and 200 *A. obscurus* and 200 *A. lineatus* has been exceeded resulting in higher catches.
The verify the efficiency of the biological treatment a row was left untreated and a statistical ANOVA - single factor analysis was applied on the tubers' weight and number from 3 repetitions of 5 meters from the untreated row (V1) and 3 repetitions of 5 meters from one treated row (V2) (Table 9).

Table 9. Data used for ANOVA single factor analysis

	V1R1	V1R2	V1R3	V2R1	V2R2	V2R3
Plants number/5 m	15	17	16	13	16	13
Stems number/5 m	180	204	208	130	192	130
Fresh stem weight kg/5 m	7.3	7.5	7.7	6.5	7.5	6.5
Tubers total number/5 m	82	107	124	159	144	111
Tubers total weight kg/5 m	13.2	9.5	15.5	13.5	14	11.5
Marketable tubers number /5 m	32	5	13	54	47	44
Marketable tubers weight/5 m	6.2	1	2	10	7.7	8.3
Unmarketable tubers number/5 m	50	102	109	94	97	67

The statistical results demonstrate the *Metharizium anisopliae* and *Beauveria bassiana* fungus biological control efficacy.

CONCLUSIONS

The key moments in predicting the implementtation of integrated control strategies are, first of all, the knowledge of the time of appearance of the adult population and the period of egg-laying, in order to prevent the multiplication of larvae and to increase the destruction of eggs and first larval stages.

Secondly, the knowledge of the periods in which the larvae feed actively.

Therefore, to protect crops and identify the right time for the application of control measures is important to know, the distribution of species, their life cycle characteristics, methods of population density prediction and economic damage thresholds.

The use in crop rotation of plants of the *Brassicaceae* family (glucosinolates in the composition of these plants have an insecticidal effect).

The use of pheromone traps in large numbers can significantly reduce the adult population and slow down the reproductive cycle.

Avoid the cultivation of plants sensitive to attack on a soil previously cultivated with perennials plants.

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