Swiss trials on the control of wireworms (*Agriotes* spp.) in potatoes

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Figure 1 | Potato tuber tunnelled by wireworm. (Floriane Bussereau, Agroscope)

Abstract

Various plant protection products based on *chlorpyrifos*, *spinosad*, *spirotetramat*, *tefluthrine*, *fipronil*, *metarhizium brunneum* and *beauveria bassiana* were tested to determine their efficacy in controlling wireworms (*Agriotes* spp., Coleoptera: Elateridae) in potatoes. Three different application periods were studied: during the catch crop preceding the potatoes, the potato-planting period itself and six weeks post-planting. The efficacy of the treatments was evaluated by measuring the proportion of tubers showing signs of wireworm damage. None of the pest control methods tested apart from the *fipronil*-based product Goldor Bait® succeeded in significantly reducing the percentage of tubers with wireworm damage compared with the untreated control. The results obtained for *fipronil* appear to show that control is more effective when applied in the autumn preceding the potato crop. Wireworm pressure during these trials was very high in certain years, with between 45 to 50 % of tubers damaged in the untreated control. In future studies it would be interesting to explore the control of this pest over the entire crop rotation.

Key words: Wireworms, pest management, potato, insecticide, time of application.

Introduction

Wireworms (*Agriotes* spp., Coleoptera: Elateridae) – also known as click-beetle larvae – are highly polyphagous pests capable of causing major damage in various crops, including potatoes (Parker & Howard, 2001). The larvae tunnel into the potato tubers (Fig. 1), adversely affecting the quality of the harvest. When the proportion of tubers with holes exceeds a certain level – 7 % of tubers in Switzerland (Swisspatat, 2022) – the harvest fails to achieve its proper value, leading to major economic losses for producers.

The main species of wireworm found in field crops in Switzerland are *Agriotes lineatus* (L.), *A. obscurus* (L.) and *A. sputator* (L.) (Jossi *et al.*, 2008). The click beetle spends on average four years in the soil in its larval form on (Miles, 1942), with two periods of activity each year, from the end of March to the beginning of May and from July to October (Evans, 1944). In Switzerland, seasonal peaks are mainly seen in spring/early summer between May and June and in autumn around September (Jossi, 2001).

In the past, the product Regent® (active substance: *fipronil*) – applied to oats in the form of a seed coating – was used to control wireworm in Switzerland. The coated oats were sown as a catch crop before planting the potatoes. The product Ephosin® (active substance: *chlorpyrifos*) was subsequently used, applied in the form of granules during potato planting. The Federal Office for Agriculture (FOAG) has since withdrawn these products, revoking the approval for Regent® in 2014 and for Ephosin® in 2021. Since then, no effective solution has been available to farmers in Switzerland.

However, some alternative treatments based on entomopathogenic fungi such as *Metarhizium brunneum* (Brandl *et al.*, 2017; Eckard *et al.*, 2014; Reinbacher *et al.*, 2021; Rogge *et al.*, 2017) and *Beauveria bassiana* (Ester & Huiting, 2007) are available. Their efficacy may vary depending on the species of *Agriotes*.

This paper presents the results of trials conducted between 2015 and 2019 mainly derived from the "Innovative strategies for wireworm control 2015–2017" project. In the context of this project, this study focussed mainly on optimising the efficacy of chemical active substances still available on the market based on the application period.

Methods

The wireworm control trials in potatoes were conducted between 2015 and 2019 at La Frêtaz (Vaud – VD), at an altitude of 1200 m. The potatoes were planted in May each year after four years of grassland. The potato variety Amandine was planted in 2015 and Erika between 2016 and 2019.

The different treatments tested are outlined in Table 1. They comprised the following active substances (AS): *chlorpyrifos, spinosad, spirotetramat, tefluthrine, fipronil, metarhizium brunneum* and *beauveria bassiana*.

Carriers for the products were used, depending on the method. These consisted of oats (140 kg/ha) or bait comprising maize starch (10 kg/ha). These carriers were chosen because they release CO_2 molecules which attract the wireworms (Barsics et al., 2014; Doane *et al.*, 1975), thereby promoting contact between the wireworms and the different active substances.

Three control periods were defined:

- autumn control in the catch crop preceding the potatoes (2016 and 2017)
- control during potato planting
- post-planting control

The reference product Goldor Bait® was chosen because its active substance *fipronil* is identical to that used in the product Regent® which effectively controls wireworm (Jossi, 2001) and was widely used prior to its withdrawal in 2014. It was applied at the same time as sowing the oat catch crop and during planting of the potatoes. In all the trials, the potato tubers were planted in mounds 75 cm apart with 33 cm between each plant.

Control in the catch crop preceding the potatoes

The tested products were applied in the form of coated oat grains (140 kg/ha) which served as both carrier and catch crop. The grains were sown in August/September. The potatoes themselves were planted the following year. Each plot consisted of six rows of 25 plants. The trials were conducted in 2016 and 2017.

Control during potato planting

Different treatments were applied directly to the mounds during potato planting. The coated oat grains, granules or bait were incorporated into the mounds. Each plot consisted of four rows of 25 plants. These trials were conducted in 2015 and 2016.

Post-planting control

Since wireworm attacks often occur in late summer (Swisspatat *et al.*, 2022), a second control period later in the season was also tested. An application six weeks after planting was carried out in the potato rows using bait or granules in order to better target the timing of the use of plant protection products according to the period of wireworm attack. These trials were conducted in 2017 and 2019. Since the products Velifer® and Attracap®, both based on entomopathogenic fungi, were not tested in the preceding trials, an additional treatment during planting was added. The reference product Goldor Bait® was applied at the time of planting according to the recommendations for use. Each plot consisted of four rows of 25 plants.

Observations

Wireworm damage was evaluated in accordance with the European and Mediterranean Plant Protection Organization standard PP1/46 (EPPO, 2005). A minimum of 100 tubers per plot were evaluated after harvesting (BBCH99). The tubers were taken from the two central mounds in each plot. After washing, the tubers were divided into two categories: no sign of damage or at least one sign of damage associated with wireworms (holes, tunnels).

Statistical analysis

An analysis of variance (ANOVA) test was conducted on all data using a linear model. The proportion of tubers with wireworm damage was measured, then the difference between the control and the different treatments was evaluated using a Dunnett's test. All statistical analyses were conducted with R 4.2.2 (R Core Team, 2022).

Results

Control in the catch crop preceding the potatoes

With the exception of the reference product Goldor Bait®, the different products tested failed to significantly reduce wireworm damage compared with the untreated control, i.e. uncoated oat grain (Dunnett's test) (Fig. 2). Despite significant wireworm pressure (46% of tubers damaged in the untreated control), the reference product Goldor Bait® proved 89.6% effective (Dunnett's test $p<0.001$) (4.8% of tubers with wireworm damage), enabling the harvest to be marketed under Swiss conditions.

Control during potato planting

Apart from Goldor Bait® ($p<0.001$), the application of different treatments during potato planting failed to control damage caused by wireworms compared with the bare-soil control (Dunnett's test) (Fig. 3). With

Table 1 | Treatments and active substances tested in the wireworm control trials in potatoes conducted at Agroscope's La Frêtaz (VD) site between 2015 and 2019. Goldor Bait® corresponds to the positive control, uncoated oats and bare soil to the negative controls.

Product	Active substance	Control in the catch crop preceding the potatoes (2016 and 2017)	Control during potato planting (2015 and 2016)	Post-planting control (six weeks) (2017 and 2019)	Formulation used
Pyrinex®	Chlorpyrifos 500 g/ha	X	X	X	coated oat grains/bait
Audienz®	Spinosad 96 g/ha	X	X	X	coated oat grains/bait
Movento SC®	Spirotetramat 75 g/ha	X	X		coated oat grains
Product 1	Téfluthrine 100 g/ha		X	X	granules
Ephosin®	Chlorpyrifos 500 g/ha		X		granules
Attracap®	Metarhizium brunneum strain Cb15-III 4.8 × 1011 spores/ha			X[1]	bait
Velifer®	Beauveria bassiana strain PPRI 5339 1.2 × 1013 spores/ha			X[1]	liquid (planting) / coated bait (post-planting)
Goldor Bait®[1] (control)	Fipronil 50 g/ha	X	X	X[2]	bait
Uncoated oat grains (untreated control)	–	X			
Bare soil (untreated control)	–		X	X	

[1] supplementary treatment applied only during planting
[2] applied only during planting

22.8% of tubers showing wireworm damage on average, Goldor Bait® had an efficacy of 54.7%. Overall, the proportion of tubers with wireworm damage was too high to enable the crop to be marketed under Swiss conditions.

Post-planting control

Treatments involving chemical pesticides or entomopathogenic fungi applied six weeks after planting failed to significantly reduce the proportion of tubers damaged by wireworm compared with the bare-soil control.

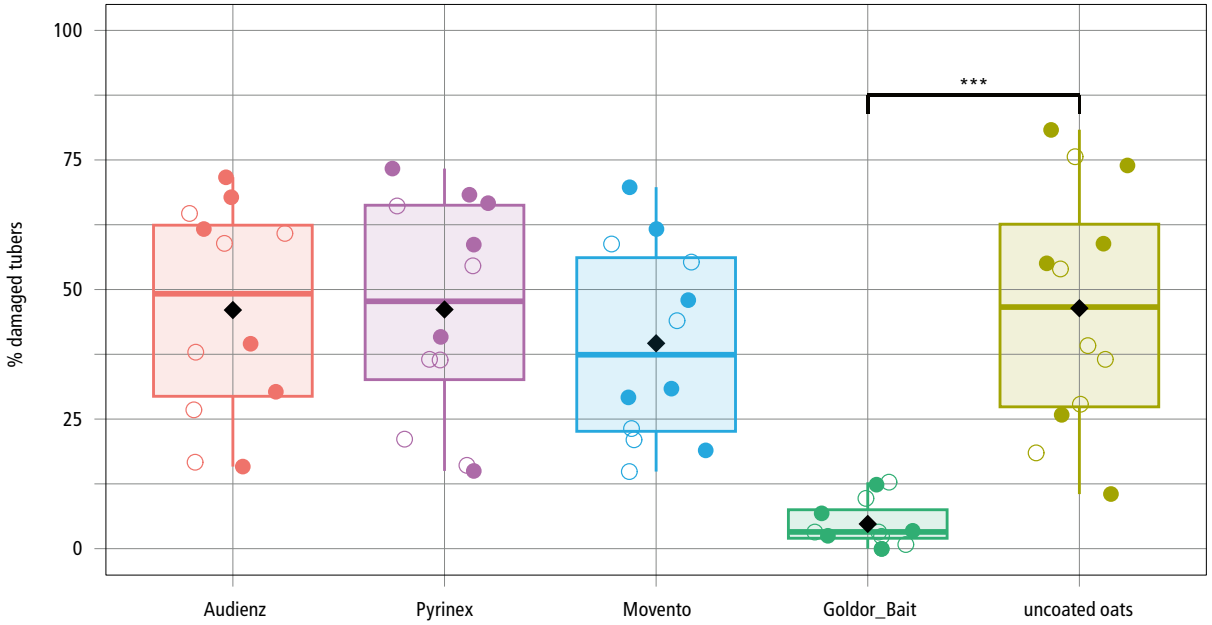

Figure 2 | Percentage of potato tubers with wireworm damage in 2016 (blank circles) and 2017 (filled circles) on the La Frêtaz (VD) site as a function of the treatments used in the catch crop preceding the potato crop. The diamonds represent the mean for each treatment. Significant differences compared with the uncoated oat control are represented as follows: *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001 (Dunnett's test).

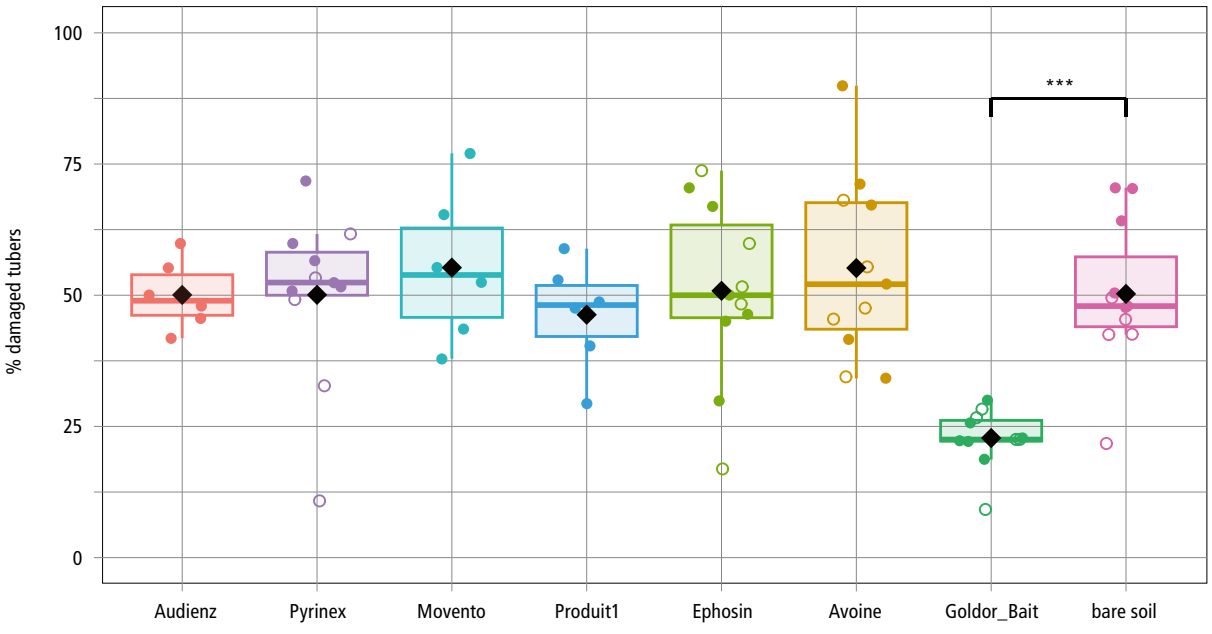

Figure 3 | Percentage of potato tubers with wireworm damage in 2015 (blank circles) and 2016 (filled circles) on the La Frêtaz (VD) site as a function of the treatments used during planting. The diamonds represent the mean for each treatment. Significant differences compared with the bare-soil control are represented as follows: *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001 (Dunnett's test).

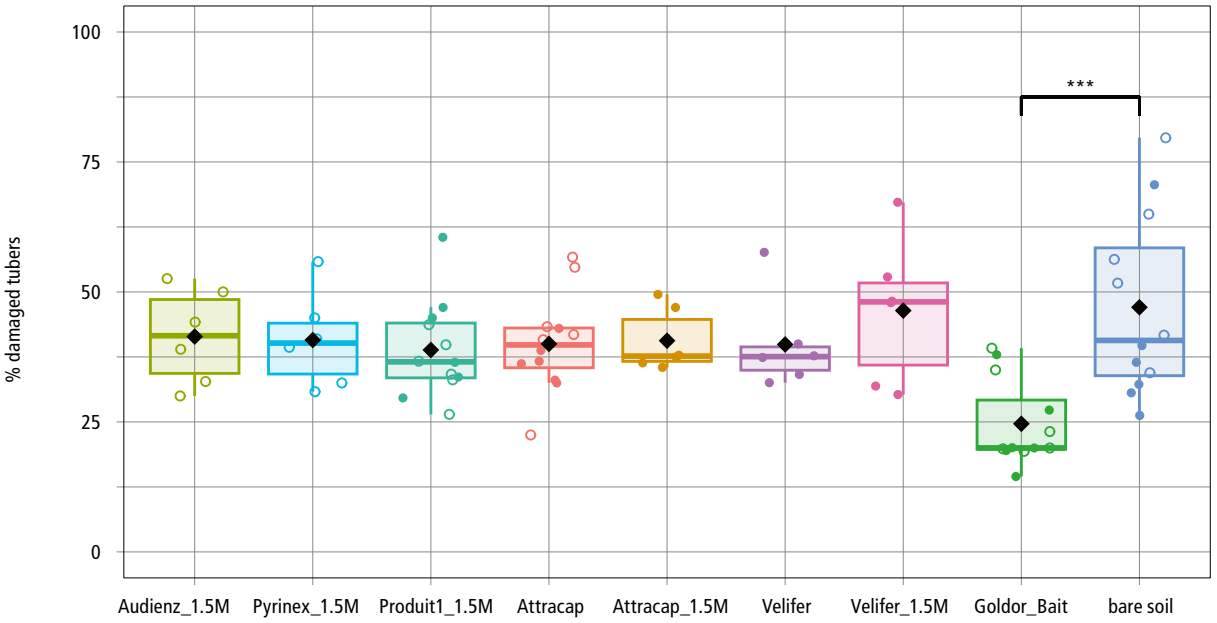

Figure 4 | Percentage of potato tubers with wireworm damage in 2017 (blank circles) and 2019 (filled circles) on the La Frêtaz (VD) site as a function of the products used during planting or six weeks post-planting (1.5M). The diamonds represent the mean for each treatment. Significant differences compared with the bare-soil control are represented as follows: *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001 (Dunnett's test).

Only the reference product Goldor Bait® (applied during potato planting) showed a significant difference (Dunnett's test $p < 0.001$) with an efficacy of 47.7 % (24.6 % of tubers damaged compared with 47 % in the bare-soil control [Fig. 4]). None of the treatments tested can be considered effective because the harvest could not be marketed (> 7 % of tubers damaged).

Discussion

Wireworm pressure was high throughout the trials, enabling us to evaluate the efficacy of the products tested. However, this high pressure may also have masked a potential partial effect of some products.

In these trials, *tefluthrine* contained in Product 1 failed to reduce wireworm damage. This active substance has been shown to have a good repellent effect in the laboratory but does not kill the insect (Van Herk, Vernon, & Roitberg, 2008; Van Herk *et al.*, 2015)

The use of *chlorpyrifos* (Ephosin® and Pyrinex®) failed to reduce the proportion of tubers with wireworm damage, regardless of the period of application. In the laboratory, Van Herk *et al.* (2015) showed that the repellent effect of *chlorpyrifos* was relatively weak at a dose of 50 g AS/100 kg of seed. In comparison, the dose we used in our field trials was seven times higher.

It is worth noting that the active substance *chlorpyrifos* has since been withdrawn in Switzerland (deadline 2021).

The active substances *spinosad* (Audienz®) and *spirotetramat* (Movento SC®) show no efficacy in reducing wireworm damage in potato tubers. This lack of efficacy was also demonstrated by Van Herk *et al.* (2015) in laboratory trials. In fact, these two active substances do not cause mortality in wireworms. Only *spirotetramat* showed a slight repellent effect.

Fipronil (Goldor Bait®) is the only product which significantly reduced wireworm damage during the trials. Now banned in Switzerland and in Europe, *fipronil* is no longer available on the market. However, its application in the trials served as a reference point for the percentage of tubers with wireworm damage obtained when using a treatment reputed to be effective (Van Herk, Vernon, Tolman, *et al.*, 2008). Despite its reported efficacy, *fipronil* has not always guaranteed adequate protection in the event of heavy wireworm pressure.

In 2016, the proportion of tubers with wireworm damage was significantly lower when the product Goldor Bait® was applied in the autumn before potato planting compared with during potato planting ($p < 0.001$). It was found to be 89.6 % and 54.7 % effective respectively. Furthermore, with the autumn application, the proportion of damaged tubers was below the 7 % threshold for acceptability for a marketable harvest.

The period of implementation of wireworm control measures plays a key role in their success and in their level of efficacy. Wireworm activity in the soil fluctu-

ates throughout the year with peaks between May and June and in September (Jossi, 2001), when control measures are essential. Premature treatments undertaken before the larvae become active (e.g. during planting from March to April) would have the effect of reducing efficacy. Nonetheless, it should be borne in mind that the application period that ensures maximum efficacy may vary from one product to another, depending on its mode of action. The products based on entomopathogenic fungi may behave differently to the synthetic products because sporulation is required before wireworms can be infected (Reinbacher *et al.*, 2021).

Conclusions

Apart from the reference product Goldor Bait® (*fipronil*), the different products tested failed to effectively control wireworm damage in potatoes. Given the very high wireworm pressure, it is possible that our trials failed to detect the partial efficacy of some products which would have been detectable in conditions of low to moderate pressure. Wireworm control remains a complex issue due to this pest's long life cycle, the potential presence of several different species at different larval stages, and finally, the difficulty in pinpointing severely affected zones within a single plot. As we have observed with Goldor Bait®, the period of implementation of the control measures is a key parameter that must be taken into consideration in future research. The option of control measures over the entire rotation is an interesting prospect to explore, particularly in the case of entomopathogenic fungi (Reinbacher *et al.*, 2021). ■

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