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ORIGINAL PAPER

# Baiting to protect maize against wireworms

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**Abstract**

Wireworms cause considerable damage to a wide range of crops, including maize which is susceptible to attack from emergence to the 10 to 12 leaf stages. One control strategy involves limiting the exposure of young maize were performed with granulated cereal-based baits. Then, this work was subsequently pursued and intensified with experiments based on the use of trap plants. These experimental works provided a description of the implementation conditions, e.g. choice of trap plant species, density, and positioning relative to maize seedlings—in which these trap plants can be used for the protection of maize crops against wireworm attacks. The technique that gave the more promising results in our experiments was based on the use of a mixture of wheat and maize as bait plants. Thus, the protection of maize against wireworm attacks has an efficacy of 55 to 60%, close to the level of protection of the chemical products currently available in Europe. This easy-to-use and effective strategy could help farmers reduce the use of insecticides in the future. Our work also allows us to identify the current benefits and weaknesses of this strategy and to propose research directions to optimise its effectiveness and facilitate its implementation by farmers.

**Keywords** Wireworms · Maize · Bait · Trap crops · Protection

## Introduction

Wireworms, the larval stage of click beetle (Coleoptera: Elateridae) cause considerable damage to a wide range of crops (Traugott et al. 2015), including maize. As the principal pest of this crop in France, about 25% of the area under maize is exposed to wireworms, and the potential yield loss has been estimated at about 8% of the national production of maize grain in the absence of insecticide protection (Thibord 2017).

In Europe, maize growers currently protect seedlings against wireworm attack with microgranules containing an active ingredient from the pyrethroid family with an efficacy of 50 to 75% (Arvalis, *unpublished data*). There is no effective solution for protecting maize against wireworms in organic agriculture. There is an urgent need to identify new and more effective solutions for the protection of maize seedlings against wireworms for conventional and organic maize crops.

Wireworms locate the plants they attack through substances released during seed germination and plant growth. These substances are mainly $CO_2$ (Doane et al. 1975; Barsics et al. 2014; Cooper et al. 2019) and volatile organic compounds (VOCs; La Forgia et al. 2020, La Forgia et al. 2021). Although research is underway to identify the VOCs of interest, this knowledge has already been used for a long time to propose effective traps for wireworms (Kirfman et al. 1986) or more recently alternative crop protection strategies against wireworms. Thus, trials were performed with an alternative source of food based on starch granules (Chaton et al. 2007; Sharma et al. 2019) or plants (Staudacher et al. 2013; Landl and Glauninger 2013; Vernon et al. 2015; Adhikari and Reddy 2017; Sharma et al. 2019) used as bait to divert larvae from several crops, such as strawberry, potatoes or wheat.

Based on current knowledge concerning the interactions between wireworms and susceptible plants, we conducted experiments in order to propose an easy-to-use and effective strategy to protect maize against wireworms. The objective was to decrease the exposure of maize plants to wireworm attack between emergence and the 6- to 8-leaf stage, a period

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during which maize plantlets are even more susceptible to attack compared to later leaf stage. The baits used in the early studies consisted of granules based on cereal starch. Studies have been pursued and intensified over the last 10 years by focusing on trap crops—or companion plants of maize crops—used as bait. Based on the results of these studies, we can describe the conditions in which trap crops are likely to be sufficiently effective to be potentially useful for protecting maize crops against wireworms. This work also highlights the limitations of strategies based on trap crops in suboptimal implementation conditions.

## Materials and methods

### Experimental set-up

The experiments were performed in southern Nouvelle-Aquitaine (Landes, Pyrénées-Atlantiques) and in Brittany (Morbihan), in fields naturally infested with large populations of wireworms and significant wireworm damage observed the previous year (often on maize). Wireworms are mainly *Agriotes sordidus* in Nouvelle-Aquitaine and *Agriotes lineatus* in Brittany (morphological identification).

The various treatments were compared in an experimental set-up consisting of microplots of four rows by 10 m (or three rows by 20 m for trials performed before 2009), with four replications in each location. The experimental treatments were compared with a control treatment devoid of insecticide protection and a reference treatment consisting of an active ingredient applied either as seed treatment (imidacloprid, thiamethoxam) or in-furrow granules when the active ingredient contained carbofuran, tefluthrin, cypermethrin, or lambda-cyhalothrin, depending on the year and the reference product available.

We counted the number of maize plants (those of the crop, not the trap plants) at emergence (3-leaf stage, BBCH13) with and without symptoms of wireworm attack on the central two rows (or the central row for three-row microplots) for each elementary plot. Assessments of number of plants with and without damage of wireworms were carried out on three or four different dates between the 3-leaf stage (BBCH13) and the 9- to 10-leaf stage (BBCH19), to obtain the number of plants that disappeared between each date due to wireworm attacks (and to ensure that the missing plants were indeed attributable to wireworm attack). The percentage of plants attacked by wireworms was calculated for each assessment date carried out after the 3-leaf stage, by dividing the number of plants that were missing (compared to the assessment realised at the 3-leaf stage) or present with symptoms of wireworm by the total of plants counted (with and without symptom) at the 3-leaf stage. The results are presented as the mean of percentage of plants attacked (missing plants and plants still present but with damage). In some trials where plants with damage of wireworm were high ($>30\%$ of plants with damage of wireworms in the check untreated), two central rows of each plot were harvested in silage or grain in order to compare the yields between treatments.

The statistical analysis was carried out in two steps: (i) The rate of plant attack (including missing plants and plants with damage) from the last assessment of each trial was transformed (arcsine). These data are then analysed with the statistical software STATBOX by an analysis of variance and means separated using Newman–Keuls test and (ii) the trials were then grouped by integrating the residual variance and the degrees of freedom of each trial, followed by analysis of variance (Newman and Keuls test).

### Experimental treatments

Diverse experimental treatments were compared with different types of bait applied at different rates or densities and with different spatial and temporal distributions.

#### Nature of the bait

The baits evaluated were either bait granules or trap crops. Bait granules essentially consisted of durum wheat starch (380 granules/g), with or without an associated active ingredient (0.5% fipronil, 0.8% cypermethrin). Trap crops were grown from seeds sown directly in the soil, to generate plantlets likely to attract wireworms. Various species from the Poaceae family susceptible to wireworm attack were compared, in which mainly wheat, maize, and barley. These species were evaluated individually or in mixtures.

#### Bait rate

The dose of bait used depended on its nature and its position within the plot. Bait granules were applied at doses of 5 to 20 kg/ha. For trap plants, we sowed seeds at a rate of 60 to 360 kg/species/ha. Some treatments were a mixture of two species. Rate calculations took into account the thousand grain weight of the trap plant seeds and whether the seeds were spread over the soil and buried in the upper 10–15 cm of soil such that the distance between seeds was between 4.6 cm for the highest density and 13.6 cm for the lowest density.

#### Spatial positioning of the bait

Various bait positions were compared in order to find a compromise between a location close to the row of maize seeds to maximise the chances of the wireworms finding the bait before finding a maize plantlet and far from the row of maize seeds to avoid attracting the wireworms to the plantlets of the maize crop and to prevent strong competition between the trap plants and the crop (but at the risk of wireworms finding and attacking maize plantlets before finding the bait).

Bait granules were placed directly in the sowing furrow, in the inter-row space with a coulter, or broadcast over the soil surface and then incorporated into the upper 10–15 cm of soil immediately before the sowing of the maize crop.

The trap crop seeds were positioned as follows: (1) on either side of the crop rows, with two coulters (at a depth of 10–15 cm, depending on the trial), (2) in the inter-row space at various distances from the row of maize to be protected, with a single coulter, (3) applied as a 20-, 40-, or 60-cm-wide strip in the inter-row space and incorporated into the upper 10–15 cm of soil, or (4) broadcast over the soil and then incorporated into the upper 10–15 cm of soil immediately before the sowing of the maize crop.

### Temporal positioning of the bait

In most of the experiments, baits were applied on the same day as the sowing of the maize crop. As the emergence of a trap crop several days before the emergence of the crop to be protected would be likely to increase the efficacy of the strategy, two trials were also performed to evaluate the value of sowing the trap crop 10 days before the maize crop requiring protection.

The trap plants were destroyed with herbicides from the sulfonylurea family (if maize was not used as bait plants in the trial) or cycloxydim (Stratos Ultra, a.i: cycloxydim 100 g/l, if maize was used as bait plants in the trail), when the maize crop was between the 3- and 6-leaf stages (depending on the trial).

The main experimental treatments are summarised in Table 1.

## Results

### Bait granules with and without active ingredient

Three trials were performed to compare treatments consisting of bait granules with and without an active ingredient (Cypermethrin or Fipronil) and several different granule positions at the time of sowing: placed in the sowing furrow with a diffusor of microgranular, in the inter-row space, or broadcast and then incorporated into the soil before the sowing of the maize crop. The results are presented in Fig. 1.

Bait granules with an active ingredient placed in the sowing furrow had an efficacy of 34 to 53%. In the same application conditions, the efficacy of bait granules without an active ingredient was variable. Attack rates were higher than for the control treatment in only one trial, with an efficacy of 42% recorded in the other two trials.

**Table 1** Experimental treatments based on bait granules and trap plants for the protection of maize against wireworms under evaluation between 2009 and 2021

| Bait | | Rate (kg/ha) | Position | | | Results are presented in the Figure numbers |
|---|---|---|---|---|---|---|
| | | | In the furrow | Inter-row space | Broadcast and incorporated into the soil before sowing of the maize crop | |
| Bait granules | Bait granules + cypermethrin | 12 | ✓ | ✓ | ✓ | 1 |
| | Bait granules + fipronil | 5 | ✓ | ✓ | ✓ | 1 |
| | Bait granules without an active ingredient (380 granules/g) | 12, 20 | ✓ | ✓ | ✓ | 1, 2 |
| Trap plants | Wheat (weight of 1000 grains, ~ 40 g) | 120<br>240<br>360 | | | ✓ | 3, 4, 5 |
| | Maize (grain, seed) (weight of 1000 grains, ~ 300 g) | 120<br>200<br>300 | | | ✓ | 3, 4 |
| | Wheat + maize | 60 + 60 | | Localised in 2 lines or applied over a strip 20, 40 or 60 cm wide | ✓<br>+ Temporal shift | 2, 3, 4, 5, 6<br>7 |
| | Barley | 120 | | Localised in 2 lines | ✓ | 3, 6 |

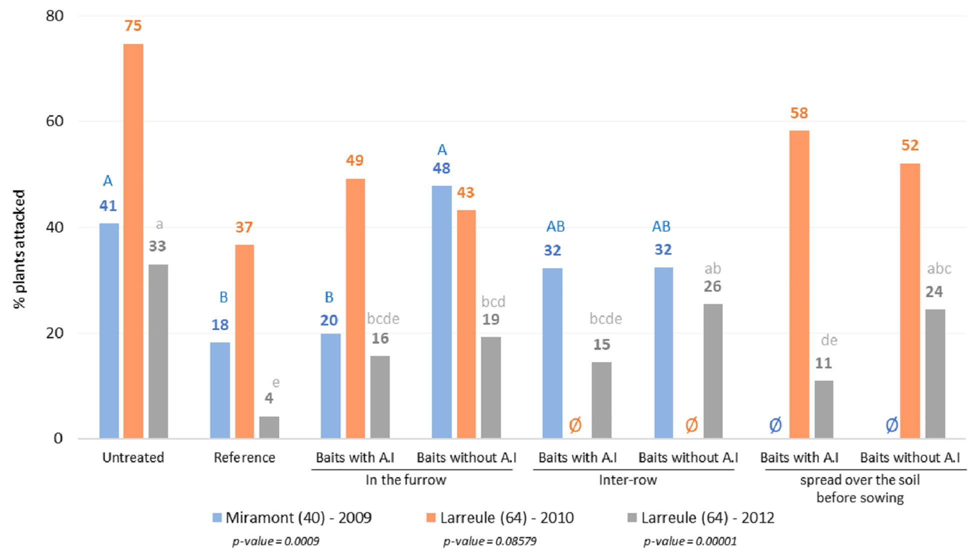



**Fig. 1** Maize protection against wireworms with bait granules with or without active ingredient (AI) and with different spatial positioning. Miramont-2009) and Larreule-2010): baits granules applied at 12 kg/ha without or with AI (Cypermethrin). Larreule (2012): baits granules without AI applied at 20 kg/ha, baits granules with AI (Fipronil) applied at 5 kg/ha. Different letters indicate a significant difference between treatments at $p$-value < 0.05 in ANOVA test

When bait granules were applied to the inter-row area or broadcast and then incorporated into the soil before sowing, protection was generally weaker than for direct placement in the sowing furrow. The utility of the active ingredient appeared to decrease with distance of the granule from the sowing furrow. For the applications farthest from the sowing furrow, the bait granules appeared to decrease wireworm attacks on maize, but with an efficacy of only 20 to 30%, regardless of the presence or absence of an active ingredient in the bait granules. The results obtained with bait granules combined with fipronil indicated that protection levels tended to be similar when the bait granules were placed farther from the sowing furrow.

## Comparison between bait granules and trap plants

The trials comparing the efficacy of bait granules and trap plants were performed from 2011 to 2013. Bait granules (without active ingredient) were applied at a dose of 20 kg/ha over the surface of the soil and then incorporated just before the sowing of the maize crop. For the trap plant treatments, a mixture of wheat and maize was applied to the surface of the soil at a rate of 120 kg/ha (60 kg of each species) and incorporated into the soil just before the sowing of the maize crop. The results are presented in Fig. 2. On average, the wheat/maize mixture of trap plants had an efficacy of 49%, whereas bait granules had an efficacy of only 18% in the same conditions.

## Trap plants: comparison of species or mixtures of species

Experiments evaluating the utility of various species of trap plant were performed from 2012 onwards. The list of species tested changed over the years. For these

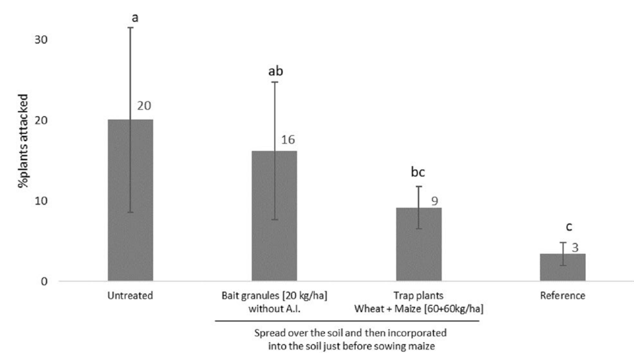


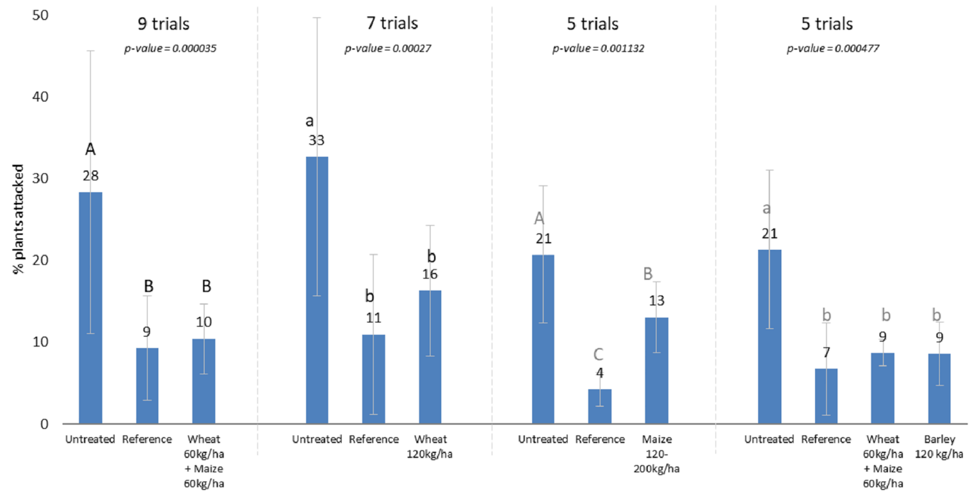

**Fig. 2** Maize protection against wireworms with bait granules and trap plants. Data are presented as means value ± SE of percentage of maize plants attacked by wireworms in three trials [Larreule (64) in 2011, 2012, 2013]. Analysis of variance with a comparison of means (Newman and Keuls test). Different letters indicate a significant difference between treatments ($p$-value = 0.00461)

comparisons, we focused on the mode of application found to be most effective in previous studies: broadcast sowing of the trap plant seeds followed by their incorporation into the soil just before the sowing of the maize crop. The results are presented in Fig. 3.

Treatments composed of a mixture of wheat (60 kg/ha) and maize (60 kg/ha) were generally the most effective, with an efficacy of 57% (mean calculated over nine trials). This level of protection is close to that obtained with the reference.

For trap plant strategies based exclusively on wheat, an efficacy of 45% was obtained on seven trials. Lower results were obtained for trap crops consisting exclusively of maize (36%). Encouraging results were obtained with trap crops based on barley, with a mean efficacy of 59% in five trials. However, crop maize was very competed by barley.

**Fig. 3** Maize protection against wireworms with trap plants used as single species or in mixtures (12 trials, 2012–2021). Data are presented as means value ± SE (*n* number of trials). Different letters indicate a significant difference between treatments (*p*-value < 0.05)




## Trap plants: comparison of densities

Two trials with low attacks, comparing either three sowing densities for wheat (120, 240, and 360 kg/ha) or three sowing densities for maize suggested that maize protection increased with increasing trap plant density (see Fig. 4). However, the efficacy of the treatment with the highest density was not significantly higher than that of the treatment based on a mixture of wheat and maize (60 kg/ha of each species).

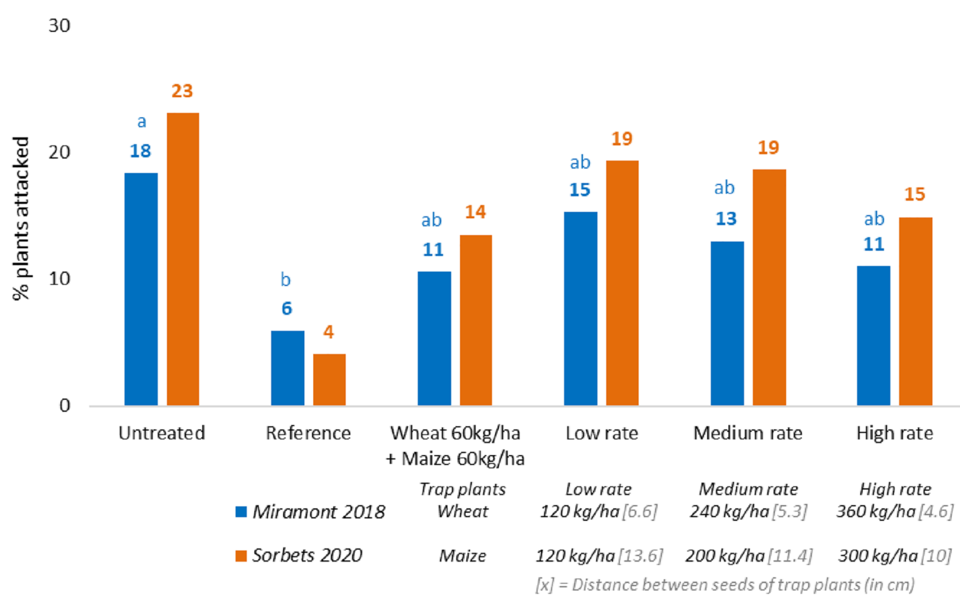
## Trap plants: effects of the trap plant strategy on maize yields

Some trials continued until the maize crop was mature, making it possible to compare yields between the different treatments evaluated. The trials, subjected to high levels of wireworm attack, yielded more precise results, with a consistent relationship between the efficacy of protection against wireworms and the yield measured at harvest for the control and reference treatments. The numbers of comparable situations were not the same, but the strategy involving the incorporation of wheat and maize seeds into the soil before the sowing of the maize crop gave a yield closer to that of the reference treatment than the strategy based on wheat alone (Fig. 5).

## Spatial positioning of trap plants relative to the crop to be protected

The studies on bait granules demonstrated a certain efficacy for protecting maize crops for baits incorporated into the soil before the sowing of the maize crop and for the positioning of baits in the inter-row space (Fig. 1). A similar experiment

**Fig. 4** Maize protection against wireworms with trap plants applied at different densities (2018, 2020). Percentage of maize plants attacked by wireworms in trials carried out in Miramont (40), 2018 (blue), and Sorbets (40), 2020 (orange). Miramont: *p*-value = 0.03. Different letters indicate a significant difference between treatments. Sorbets: *p*-value = 0.0273 (no difference between treatments)



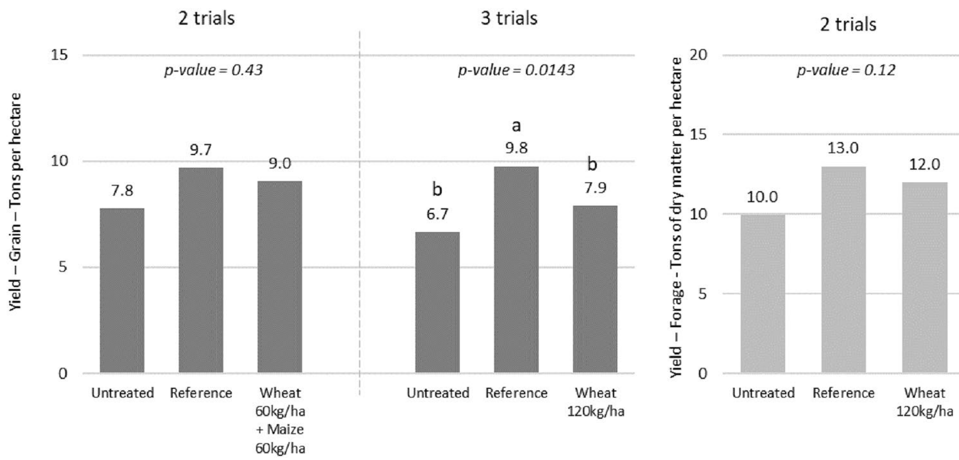


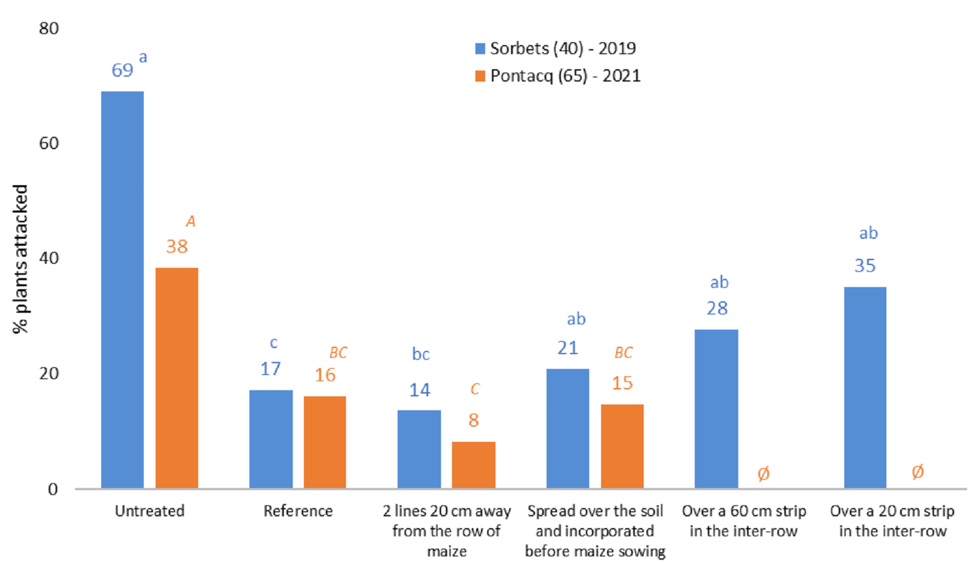

**Fig. 5** Yields of grain or silage maize with different trap plants in situation under high levels of wireworm attack (> 30% of the plants attacked in the check untreated) (2012–2019). Different letters indicate a significant difference between treatments if $p$-value < 0.05 in ANOVA test. Yield of different treatments in experiments harvested in grain (black) or silage (grey) maize. Yield of different treatments in experiments harvested in grain (black) or silage (grey) maize. Mixture of wheat and maize as trap plants is less competitive to maize crop than wheat used as trap plants

was performed for the trap plants treatment based on a mixture of wheat (60 kg/ha) and maize (60 kg/ha) or barley alone, to make it possible to compare results for trap plants in different positions: in two lines on either side of the row of maize, over a 20-cm-wide strip in the inter-row space, over a 60-cm-wide strip in the inter-row space, or broadcast over the soil and incorporated just before the sowing of the maize crop. The results (Fig. 6) demonstrate the value of positioning trap plants as close as possible to the sowing furrow, to increase the efficacy of protection against wireworm attack.

## Temporal positioning of trap plants relative to the crop to be protected

Two groups of trials evaluated wireworm damage to maize in response to the timing of sowing the trap plants. In one group of trials, the trap plants were sown 10 days prior to maize; in another group of trials, trap plants were sown on the same day as maize. Maize was protected only when the trap crop was sown on the same day (Fig. 7).

**Fig. 6** Maize protection against wireworms according to the positioning of the trap plants (2019, 2021). Sorbets (40)—2019 (blue): Trap plants = Wheat 60 kg/ha + Maize 60 kg/ha. $p$-value < 0.00001. Pontacq (65)—2021 (orange): Trap plants = Barley 120 kg/ha. $p$-value < 0.000019. Different letters indicate a significant difference between treatments at $p$-value < 0.05 in ANOVA test



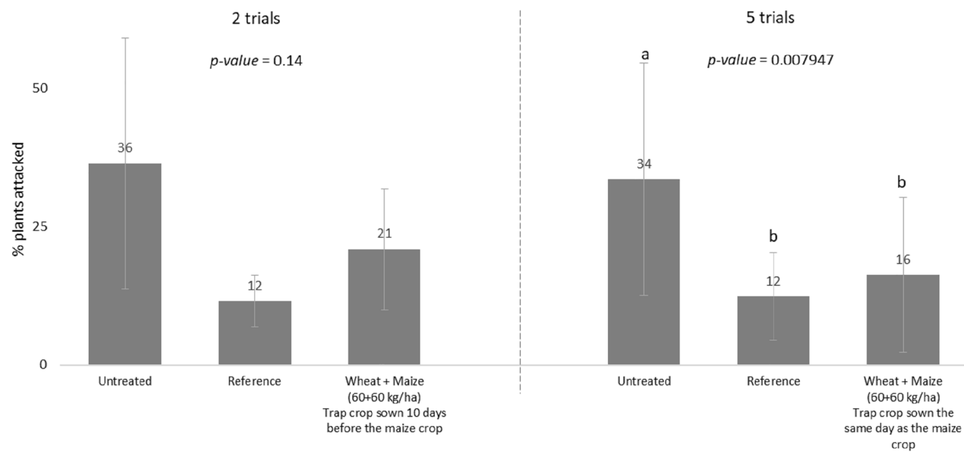



**Fig. 7** Maize protection against wireworms according to the shifting between trap plants sowing and crop sowing. Trap crop was sown 10 days before the maize crop (two trials done in 2015, 2016—on the left) or the same day as the maize crop (five trials done between 2012 and 2019—on the right). Different letters indicate a significant difference between treatments at *p*-value < 0.05 in ANOVA test

## Discussion

### Bait granules are effective, but not enough

Bait granules provided significantly less protection against wireworms than the insecticide reference. However, the percentage of maize plants attacked by wireworms was lower when bait granules were applied compared to the control without any bait granules. These results are consistent with those reported by Sharma et al. (2020) who applied 11.2 kg/ha of couscous in the furrow to protect spring wheat. The efficacy of granulated bait was demonstrated for various spatial applications: within the sowing furrow, in the inter-row area or broadcast over the soil and incorporated into the soil just before the sowing of the maize crop. For granulated bait applied further away from the row of maize (but nevertheless in the inter-row space) or well diluted within the soil (broadcast over the soil and then incorporated), without the use of Fipronil, efficacy levels of 20 to 30% were recorded. These results demonstrate the utility of baits for diverting wireworms from the plants to be protected. Such levels are, unfortunately, insufficient to ensure the satisfactory protection of maize crops.

### Trap plants have a technical advantage

When the bait granules are applied at a dose of 20 kg/ha, the average theoretical distance between two granules is 5.1 cm (calculation carried out for a burial on the 10 cm upper of the soil) and provides protection against wireworms with an efficacy average of 20% (Fig. 2). When the bait is wheat, the distance between two grains is theoretically 5.3 cm for a dose of 240 kg/ha and 4.6 cm for a dose of 360 kg/ha. These doses provide protection with efficacy of 34% and 47%, respectively (Fig. 4). This means that for distances between baits—granules or seeds—which are relatively similar, protection against wireworms is more effective in the case of bait plants than in the case of bait granules. Our results confirm that the trap crop strategy is more effective if seeds germinate and generate plants. In some experiments, we applied rice or triticale seeds which did not germinate and the results on maize protection were close to those obtained with bait granules (results not presented).

The implementation of trap plants strategy in place of granulated bait provided encouraging results. The highest levels of protection were obtained with a trap crop consisting of a mixture of wheat and maize. The efficacy of protection was lower for single-species trap crops consisting exclusively of wheat alone or maize alone. These results are consistent with the recommendation to use a mixture of maize and wheat seeds in traps in order to sample wireworms in soil (Kirfman et al. 1986).

Other cereals (barley, oats, triticale, etc.) have been evaluated for use as trap crops (only treatments for which several references are available are presented). Barley alone gave interesting results, but the wheat/maize mixture remains the treatment most consistently providing a high efficacy of protection. Those results are very consistent with the previous results which show that the diversity of plants used as bait increases the effectiveness of crop protection against wireworms (Staudacher et al. 2013).

### Trap plant seeds spread over the soil and incorporated provided the highest level of protection

The trap plants need to be located close to the crop plant to provide a sufficient degree of protection of the crop plant against wireworms. However, the closer the trap plants are to the young crop plant, the greater the competition between the two is likely to be. The most satisfactory compromise is the application of the seeds of the trap plant to the surface of the soil, for example, with a centrifugal seed drill, followed by their incorporation into the upper 10–15 cm of the soil during last preparation of the seedbed for the sowing of the maize crop, thereby making it possible to create an even distribution of the trap crop seeds in the soil. The wireworms heading towards the surface from lower levels of the soil thus come into contact with the trap plant seeds and seedlings. The attacks on the seeds and plantlets of the maize crop are therefore fewer in number, due to a dilution of the crop seeds/plants amongst trap plants. Contrary to the results obtained by Vernon et al. (2000), shifting the sowing date of the trap plant by 10 days in relation to the sowing of the main crop did not improve the efficacy of the protection in our experiments.

### The trap plants must be destroyed

The trap plant strategy gave interesting results for the protection of maize against wireworm damage, but because the traps plants ultimately compete with the maize, it could prove more damaging than wireworm attack if the trap plants are not destroyed in time.

One technique for ensuring the destruction of trap plants involves using wheat and maize varieties susceptible to cycloxydim herbicide as the trap plants and a cycloxydim-tolerant variety of maize as the crop, the applying a product for which cycloxydim is the AI, such as Stratos Ultra.

Another possibility would be to use trap plants other than maize. This approach would decrease the efficacy of protection against wireworms—although barley offered a good level of protection in our trials—but would make it possible to destroy the trap plants with an herbicide from the sulfonylurea family. However, these herbicides act more slowly and their destruction of trap plants is less systematic than with the application cycloxydim-based products. In our experimental conditions, the destruction of the trap plants with sulfonylurea herbicides was frequently insufficiently effective and the trap plants therefore had highly deleterious effects on the crop.

Mechanical destruction of the trap crop could also be envisaged and may be the only possible solution in the context of organic agriculture. The strongest constraint remains row management. Sowing the trap plants in the inter-row space facilitates their elimination by hoeing, but decreases their efficacy against wireworms. Conversely, the incorporation of the trap plant seeds into the soil provides better protection against wireworms, but results in a greater threat to the crop, particularly due to the difficulty of weed removal within the row (depending on the material available).

The destruction of the trap plants is a key step that should not be neglected. It is strongly recommended to take this critical point into account when developing technical schedules, from the choice of the variety of maize to be grown (preferentially a cycloxydim-tolerant variety) to the choice of weed control strategy (chemical or mechanical).

## Conclusion

Previous studies have demonstrated the potential interest of trap plants to protect spring wheat (Sharma et al. 2019), strawberry (Vernon et al. 2000), or potatoes (Landl and Glauninger 2013; Vernon et al. 2015) against wireworm attacks. Our results demonstrate that the use of trap plants is an interesting lever of action to also protect maize crops against wireworms: A mixture consisting of wheat (60 kg/ha) and maize (60 kg/ha) from a variety sensitive to cycloxydim applied directly to the soil and then incorporated into the 10–15 upper cm of soil before sowing a variety of maize tolerant to cycloxydim presents the best compromise between effectiveness of protection against wireworms, ease of destruction of trap plant (in conventional agriculture), and limited competition of trap plant on maize crop. This crop management technique protects maize against wireworm attacks with an efficacy of 55–60%. This level of effectiveness is close to that of chemicals currently available in Europe. The implementation of this strategy in crop management could help farmers to reduce the use of insecticide products without increasing use of herbicide product.

The incorporation of trap plant seeds spread over the soil and incorporated into the soil just before maize sowing is very easy to use and does not require any adaptation of the equipment. The main obstacle to the technique is that the number of cycloxydim-tolerant maize varieties currently offered to farmers is quite limited. Further research is needed to optimise the choice of trap plant varieties given the differences in susceptibility between varieties of maize (La Forgia et al. 2020) and wheat (Higginbotham et al. 2014). The ideal trap plant would belong to another botanical family than the Poaceae family, facilitating its chemical destruction and at least as attractive as maize for wireworms.

Spatial positioning of trap plants is important too. The effectiveness of the protection can be improved by applying the seeds of the bait plants in one or two rows close to the maize sowing line. This implementation is nevertheless difficult because it makes the destruction of the bait plants more complicated and increases the risk of competition from the trap plants on the maize crop. When the trap plants are further from the row of maize, the level of protection decreases but the destruction of the trap plants is easier, especially with mechanical tools (used in organic farming).

Once the technical schedule for trap plants has been optimised, it should be possible to use this lever alone or in combination with insecticidal products (conventional or biological control). The preliminary results obtained for the combination of trap plants with insecticidal protection through microgranules added to the sowing furrow of the maize crop suggest that the efficacies of these two approaches are additive. This could make it possible to achieve a level of maize protection similar to that previously achieved with some insecticides which have recently been banned and whose efficacy for maize protection against wireworms was 85–95% (Arvalis, *unpublished data*). As for all changes in strategy involving modifications of crop management, studies are required to evaluate the consequences in the medium-to-long term. One of the key questions concerns the effect of this technique on the evolution of wireworm populations in the field. Another underlying question relates to the value of combining the use of trap plants and insecticidal protection to decrease the populations of wireworm (Vernon 2005; Vernon et al. 2015). The trap plant strategy fits into a broader approach based on a range of service plants. Its implementation can be modulated to respond to the diversity of needs and to adapt to different agronomic contexts for the production of maize.

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**Data availability** Data are available.

## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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