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Review Article

Potential Application of Pheromones in Monitoring, Mating Disruption, and Control of Click Beetles (Coleoptera: Elateridae)

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Wireworms, the larvae stage of click beetles (family, Elateridae), are serious soil dwelling pests of small grain, corn, sugar beet, and potato crops globally. Since the 1950s, conventional insecticides such as lindane provided effective and inexpensive protection from wireworms, and little integrated pest management research (IPM) was conducted. The removal of these products from the agricultural market, particularly Lindane, has resulted in increasing levels of wireworm damage to small grain, corn, and potato crops. The wireworm damage has become an increasing problem for growers, so the demand for a meaningful risk assessment and useful methods to restrict damage is increasing. However, due to the cryptic habitat of the wireworms, pest control is very difficult and leads to unsatisfying results. The prospective appropriateness of sex pheromone traps for employing management strategies against wireworm's populations was first suggested with experimentation in Hungary and Italy. Simultaneously, considerable work has been done on the identification and use of pheromone traps to monitor population of click beetles. The work has been mostly done in European and former Soviet Union countries. For this paper, we reviewed what work has been done in monitoring the click beetle which was considered as pests and how the pheromones can be used in IPM to monitor and control wireworms/click beetles. Also, the possibilities of using the pheromone-baited traps for mating disruption and control tested in the fields were summarized.

1. Introduction

Wireworms are the larval forms of click beetles (Coleoptera: Elateridae), inflicting damage to many important crops around the world, primarily through the subterranean feeding of plant roots and tubers [1]. Wireworms, the larval stage of click beetles, are serious soil dwelling pests of small grain, corn, sugar beet, and potato crops globally [2]. About 9,300 species of click beetles have been described worldwide [3]. In North America, 885 species in 60 genera have been identified [4]. These species are well known as widely distributed agricultural and horticultural pests [5]. Many of these species have affected crop industry and ranked among the most important soil dwelling agricultural pests worldwide [6]. Usually, economic damage to the field crops caused by wireworms is rare. However, the population of click beetle larvae can reach numbers high enough to cause economic damage [7]. During larval stage, which may extend over 5 years, these larvae feed on decaying matters or feed on root of crops such as wheat and rye [7].

The wireworm as pests on agricultural crops has been controlled until 2009 through the use of lindane (gamma HCH). After that, lindane was not allowed to be used due to health concerns. This insecticide was found to cause so many harmful health effects such as convulsion, vertigo, abnormal EEG pattern, cancer, endocrine disruption, and liver toxicity [8].

Since recent years, wireworm damage has become an increasing problem for growers. The demand for a meaningful risk assessment and useful methods to restrict damage is increasing. However, due to the cryptic habitat of the wireworms, pest control is very difficult and leads to unsatisfying results [9].

Soil treatment with insecticides or fumigants may be used to control wireworm effectively [10]. However, these fumigants or residual chemicals are costly and may build up large amounts of chemicals in the soil [11]. Insecticide seed treatment is reported to be cost-effective in protecting seeds and young plants because of the small amounts of insecticide used and the low cost of application [12].

Managing wireworms (Figure 2) requires regular and consistent monitoring and attentive field management. There have not been many options using biopesticides as little research work has been done. For example, Cherry and Nuessly [13] reported that azadirachtin did not cause mortality or antifeeding responses or change growth rate of wireworms. However, azadirachtin-treated soil was repellent to wireworms at up to 17 days after application.

Chemical communication plays a very important role in the lives of many insects [14]. Chemicals with an intraspecific function are called pheromones. Pheromones are substances which occur naturally and are used to communicate between organisms. Sex or aggregation pheromone-baited traps have been used to monitor and control the populations of many insect pests [15]. The composition of sex pheromone produced in female click beetles has been identified in several species and the use of synthetic pheromone-blend compositions to control click beetles is promising [5, 16].

In the USA, the identification of pheromone compounds for click beetles (wireworms) (Figure 3) was initiated in 1968. For example, valeric acid (pentanoic acid) from *Limonius californicus* [17] and caproic acid (hexanoic acid) from *L. anus* [18] were identified as pheromone compounds. However, no work was carried out after that because the chemical lindane also known as gamma-hexachlorocyclohexane was available and had been used as a seed treatment. This chemical was effective against wireworms and gave good control. However, the USEPA and WHO both classify lindane as moderately acutely toxic. The use of lindane as an insecticide was banned in 2009 in the USA and other parts of the world. Since there is no substitute for these chemicals available, wireworms became serious pests causing damage to potatoes, wheat, barley, vegetable, and other major crops throughout the world. Wireworms can attack both spring and fall-seeded crops. In spring, when soil temperature gets warm to 50°F, wireworm larvae begin to migrate upward, almost to the soil surface, where they feed on newly planted seed, seeding, and roots. When soil temperatures rise to 80°F, the larvae seek lower soil temperature which is a foot or two feet below the soil surface. Although seed treated with Gaucho (imidacloprid) gave some level of control, the monitoring of the pests has been very challenging and difficult. Pheromone-baited traps are useful in monitoring and control of insect pests [19]. The pheromone compounds have not yet been identified for North American species of wireworms. Nevertheless, the compounds have been identified for European-based wireworm species [20, 21].

Evidence for the existence of long range sex pheromones within the click beetles has been demonstrated for many species [7, 22].

In this review, we summarized the click beetle pheromone source and the practice of using pheromone in monitoring and controlling click beetles. The aim was to present the identified and synthesized pheromones and employed methodology.

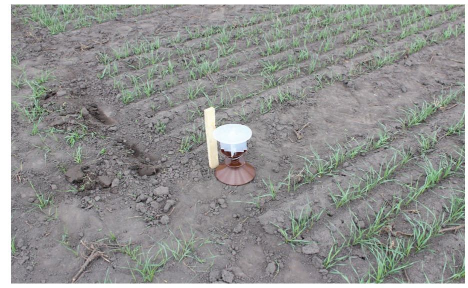

Figure 1: Yatlor funnel trap current used for monitoring click beetles.

Figure 2: Larva of the wireworm that causes damage to the crops.

Figure 3: Adult click beetle.

2. Pheromones Source and Gland Extract

In most insects, pheromones are produced by glandular epidermal cells concentrated in discrete areas beneath the cuticle, but in some species, gland cells are scattered through the epidermis of different parts of the body. For click beetles, the male attractant pheromone is produced by female pheromone glands located at the last abdominal segment [23]. The click beetle pheromone gland resembles a paired ball-like structure in the abdomen [16]. Merivee and Erm [23] conducted study on sex pheromone gland morphology in female Elaterid beetles and demonstrated brief morphological description of the female reproductive system of *Agriotes obsucurus*. They found that, for this species, the paired pheromone gland was located in the 8th segment of the female abdomen and is attached to the sternite with muscular fibers. The reservoirs of the gland are connected with the intersegmental membrane by means of thin winding excretory ducts which are dilated before opening on the body surface, forming pseudoovipositor pockets. The excretory ducts are spirally surrounded by thin muscular fibers which are functionally related to the excretion of secretion. The length of gland reservoirs in sexually mature females was 0.9–1.3 mm, width 0.25–0.35 mm. The amount of secretion in two reservoirs of one female pheromone gland was 30–40 nL [23].

For gland extraction, usually the sexually mature adult beetles are collected and sorting the sex. Female sex pheromone gland is extracted by carefully piercing the pheromone gland with a fine glass capillary and collecting the liquid inside into the capillary [24, 25]. The extracts (liquid samples inside the capillary) which are usually colorless and with mildly unpleasant smell will be analyzed by gas chromatography linked with mass spectrometer (GC-MS) in order to identify the volatiles released from pheromone glands.

3. Pheromone Identification

Pheromone of 22 species of *Agriotes* click beetles in Europe have been identified [6, 26]. In this review, we only focused mainly on the species which are considered as pests. These are *Agriotes brevis* (Candeze), *Agriotes lineatus* L., *Agriotes litigiosus* Rossi, *Agriotes obscurus* L., *Agriotes rufipalpis* Brullě, *Agriotes sordidus* Illiger, and *Agriotes ustulatus* Schaller [27].

3.1. Agriotes brevis (Candeze). The pheromones of this species were first identified by Tóth et al. [28]. The components of the pheromone were geranyl butanoate, (*E,E*)-farnesyl butanoate, geranyl hexanoate, farnesyl acetate, geranyl pentanoate, geranyl 3-methyl butanoate, and β-farnesene. From their experiment, only geranyl butanoate and (*E,E*)-farnesyl butanoate were proven to be active in the field and able to attract male click beetles to the traps.

3.2. Agriotes lineatus L. The component of the pheromone gland extracted from females revealed (*E,E*)-farnesyl acetate, neryl isovalerate, geranyl octanoate, neral, geranial, nerol, geraniol, geranoic acid, geranyl hexanoate, geranyl decanoate, methyl hexadecanoate, methyl octadecanoate, geranyl butanoate, geranyl octanoate, geranyl nonanoate, geranyl dodecanoate, geranyl octanoate, 2(Z), 6(*E*)-farnesyl acetate, neryl-3-isovalerate, 6-methyl-3,5-heptadien-2-one, myrcene, (*Z/E*)-ocimene, genranial, 2,3-epoxygeranyl octanoate, and 6,7-epoxygeranyle octanoate [6, 7, 20, 22, 26, 29–32]. However, the main component of pheromone which showed to be attractive was geranyl octanoate [6, 7, 31, 32].

3.3. Agriotes litigiosus Rossi. A few chemical compounds extracted from females have been identified. These were geranyl isovalerate [6, 22, 33] and geranyl butanoate [7, 29]. The rest of chemical compounds extracted from pheromone were identified by Tóth et al. [6]. These were farnesyl isovalerate, geranyl 3-methyl-3-butenoate, 3-methyl-2-butenoic acid, linayl, geranyl 3-methyl-2-butenoate, (*E*)-8-hydroxygeranyl, diisovalerate, and 3-methyl-3-buenoic acid [6].

3.4. Agriotes obscurus L. Geranyl hexanoate and geranyl octanoate were found to be dominant pheromone components for this species [6, 7, 26]. However, there were other compounds which were detected from the pheromone gland extracts but in trace amounts, for example, hexanoates and octanoates of nerol, 6,7-epoxygeraniol, myrcene, limonene, cis/transocimene, geranial, and geraniol [6].

3.5. Agriotes rufipalpis Brullě. There was not much known information about the pheromone composition of this species. The study done by Tóth et al. [6] revealed that no reliable analysis of pheromone gland extracts could be conducted. They failed to collect female *A. rufipalpis* in large enough numbers. However, they found that males of this species were attracted to geranyl hexanoate in the field.

3.6. Agriotes sordidus Illiger. Tóth et al. [6] tried the traps baited with geranyl hexanoate and found that *A. rufipalpis* males were attracted to these compounds. They then extracted the female pheromone glands and found from analysis that geranyl hexanoate and (*E,E*)-farnesyl hexanoate were the major peaks from the retention times.

3.7. Agriotes sputator L. Geranyl butanoate was reported to be the main pheromone component for this species [6, 26, 31]. However, Tóth et al. [6] also detected 6,7 epoxygeranyl butyrate as minor component and also other terpenes such as geraniol, neryl butyrate, geranyl and (*E,E*)-farnesyl hexanoates, geranyl linalool, and several terpenoid epoxides such as the butyrates of 2,3-epoxy-nerol/geraniol and 2,3,6,7-diepoxy-nero/geraniol, which were present in very small trace amounts.

3.8. Agriotes ustulatus Schaller. The dominating component in the pheromone gland extracts was (*E,E*)-farnesyl acetate [6, 26, 32]. Other compounds also were found in trace amounts, for example, geranyl hexanoate and (*Z,E*)-farnesyl hexanoate. Moreover, trace amounts of terpenoid hydrocarbons were shown such as (E)-β-farnesene, (*Z,E*)- and (*E,E*)-α-farnesene, β-bisabolene, and (E)-α-bisabolene [6].

4. Synthesis of Click Beetle Pheromones Used in the Fields

The synthetic click beetle main sexual attractants based on the studies of European scientists [6, 15, 27, 34, 35] were synthesized and applied in the fields. In this review, we summarized the attractiveness of the synthetic sexual pheromone compounds being used in each click beetle species considered as pests.

4.1. Agriotes brevis (Candeze). The study done by Tóth et al. [6] showed that geranyl butanoate and (*E,E*)-farnesyl butanoate were the main compounds found from the female pheromone gland extract and proved to be active in the field in attracting males to the traps with these compounds' lures. Their study showed that the presence of both semiochemical compounds could efficiently attract male *A. brevis* towards Austria, Bulgaria, Italy, and Slovenia. However, in Hungary, Romania, and Croatia, the traps baited with these compounds caught other species (*A. sputator*) more than they did with *A. brevis*. They hypothesized that the content of geranyl butanoate played role in catching *A. sputator* because the geranyl butanoate also attracts this species.

4.2. Agriotes lineatus L. Geranyl octanoate was used as lures to attract *A. lineatus* because this compound has been proven to be main pheromone component for this species [6, 7, 31, 32]. Single geranyl octanoate compound attracted fewer individuals than the combinations of more than one single compound. In Switzerland the traps bait containing 10% geranyl butanoate added to geranyl octanoate attracted a total of 273 individuals, whereas nonindividual was found in the traps baited with only geranyl octanoate [15]. The ratio of 1 : 10 mixture between geranyl butanoate and geranyl octanoate has been applied in the field trials in Europe and reported to be efficient in capturing *A. lineatus* in United Kingdom, Germany, Austria, Switzerland, Italy, Slovenia, Croatia, Romania, Bulgaria, Greece, Spain, France, and Hungary [6]. In North America, this 1 : 10 mixture also showed good result in capturing *A. lineatus* in Canada [36].

4.3. Agriotes proximus Schwarz. The identified dominant pheromone for this species was first reported as (*E,E*)-fearnesyl acetate and neryl isovalerate [22, 26]. Tóth et al. [20] tried these 2 compounds as lures in the field to capture adults, but there was no catch at this entire species in the traps. Later, Vuts et al. [37] did analyses of collected volatiles from air entrainment samples and found that these 2 compounds were not detected either in gland extracts or in head space samples of *A. proximus* females. What seemed to be strange was that when Tóth et al. [20] applied geranyl butanoate and geranyl, octanoate with the ratio of 1 : 1 in order to capture *A. lineatus* the blend could also capture a large number of *A. proximus*. These results were mystifying because chemical studies showed that geranyl butanoate and geranyl octanoate were detected only in little trace amounts in *A. proximus* female pheromone glands [6, 26, 31]. However, when applying the blend of geranyl butanoate and geranyl octanoate in the field, the ratio of 1 : 10 was revealed to capture more adults than the ratio of 1 : 1 [37].

4.4. Agriotes litigiosus Rossi. Geranyl isovalerate was reported to be the main pheromone of this species [22, 27, 32]. In 1983, Yatsynin and Rubanova [38] combined the (*E,E*)-farnesyl isovalerate or (*E*)-8-hydroxygeranyl 1,8-diisovalerate with geranyl isovalerate. They found the synergistic effect which resulted in enhancing the capture of *A. litigiosus* var. *tauricus*. However, Tóth and Furlan [27] found that this combination of mixture did not influence catches in any of the morphological forms of *A. litigiosus*. Therefore, only traps baited with single compound (geranyl isovalerate) were used in Europe-wide trapping test [27]. The result from this trial did not prove to be promising. In some parts of Europe, for example, Italy, Austria, and Greece, the individuals were captured a lot. But for other parts such as Croatia, there were some other species captured from the traps baited with this compound. There was no consistency of capturing *A. litigiosus* using this main pheromone compound. More repeated studies should be conducted to prove the efficacy of the traps baited with geranyl isovalerate.

4.5. Agriotes obscurus L. Geranyl hexanoate was reported to be dominant pheromone of *Agriotes obscurus* and for single compound of this chemical without adding with any compounds could attract *A. obscurus* efficiently [31, 32]. However, previous study done by Borg-Karlson et al. [7] revealed that there was the other dominant pheromone compound also and this compound was identified as geranyl octanoate. Later on, Yatsynin et al. [26] and Tóth et al. [6] found the same results that geranyl hexanoate and geranyl octanoate were dominant pheromone compounds and the presence of both compounds was needed for attracting adults. The study was conducted on how to optimize the ratio between these two compounds. Tóth et al. [6] found no significant difference in applying 2 : 1, 1 : 1, and 1 : 2 mixture ratios. Therefore when applying the traps with lures in the field, only traps baited with 1 : 1 between these two compounds were adequate to large numbers of *A. obscurus*. This practice was effective in capturing adults in United Kingdom, Germany, Switzerland, Italy, Slovenia, Croatia, Romania, and also Canada [27].

4.6. Agriotes rufipalpis Brullé. Geranyl hexaonate was found to be dominant pheromone for this species. These compounds were used as lures by Tóth et al. [39]. The result showed that traps baited with geranyl hexanoate performed well in capturing *A. rufipalpis* in Austria, Serbia, Greece, Romania, and Hungary.

4.7. Agriotes sordidus Illiger. Analysis of gland female pheromone gland extracts showed dominant peaks at the retention times of geranyl hexanoate and (*E,E*)-farnesyl hexanoate [6]. However, when traps baited with only geranyl hexanoate alone or the combination of geranyl hexanoate and (*E,E*)-farnesyl hexanoate did not reveal any significant differences in catching adults [27], the synergistic effect between these 2 compounds did not occur. Traps baited with only geranyl hexanoate have been used in Italy, France, and Spain and showed good results in capturing large numbers of adult males [27].

4.8. Agriotes sputator L. The main component of pheromone for *A. sputator* was reported as geranyl butanoate [6, 26, 31]. Siirde et al. [31] stated that adding neryl butanoate to geranyl butanoate could enhance the catch of adults. Yatsynin et al. [26] also reported synergistic effect by adding (*E,E*)-farnesyl hexanoate alone or together with geranyl propionate mixed with geranyl butanoate as blend. However, when these blends from both studies were tried again by Tóth [16], only geranyl butanoate alone without addition of any other compounds worked the best in catching the adults. The traps with geranyl butanoate lures were very effective in capturing adults in northern and central Europe and Canada [27].

4.9. Agriotes ustulatus Schaller. The dominant compound from pheromone extracts of this species was (*E,E*)-farnesyl acetate [6, 26, 31, 32]. The traps with lures of (*E,E*)-farnesyl acetate performed well in attracting the adult beetles in Europe. There are some species accidentally captured by using some compounds such as geranyl butanoate used not only to capture species *A. sputator* but also attract species *A. proximus*. However, these species which were accidentally captured were not reported to be pests.

5. Pheromone-Based Monitoring and Control

The application of traps baited with sex pheromones to lure male insects has been an excellent tool for monitoring pest populations in survey and integrated pest management (IPM). A lot of insect sex pheromones can be synthesized and conventionally used in pest monitoring and controling. The advantages of using pheromone traps are (1) able to detect early pest infestation, for example, the first detection of migratory pests, (2) to easily define areas of pest infestations, (3) to able to track the establishment of pest populations, and (4) to help in decision making of management [40]. However, in order to apply effective pheromone trapping system and result in large number of pest catches, this requires careful preparation, handling, and selection of pheromone traps and lures, as well as proper trap placement [40]. Females of some *Agriotes* spp. are known to produce sex pheromones [41]. Oleschenko et al. [24] reported that male *Agriotes litigiosus* were attracted to geranyl isovalerate and male *A. gurgistanus* were attracted to geranyl butyrate [24]. Female sex pheromones were identified as n-dodecyl acetate [42] and as (E)-9, 11-dodecadienyl butyrated and (E)-9, 11-dodecadienyl hexanoate in *Melanotus sakishimensis* Ohira [43]. Nagamine and Kinjo [44] reported on the population parameters of *M. okinawensis* by using water pan traps baited with synthetic sex pheromone in the field. Further density and dispersal distance of this species were successfully estimated by Kishita et al. [45] by using mark-recapture experiments over an agricultural field on Ikei Island (Japan).

6. Role of Pheromone Traps in Monitoring the Click Beetle

The traps baited with pheromone to attract click beetles were used since 1997 [46]. Different types of traps were tried to capture beetles using pheromones as baits. Development of a trap model suitable for catching the different species was conducted [46]. In the beginning, the bottle traps which were funnel traps were made at home from 2-litter transparent plastic bottles as the prototype traps. Then VARb traps were invented by using the plastic CSALOMON VAR funnel traps. After that the TAL traps were introduced to the capturing of click beetles. The development was still ongoing until the YATLOR traps were made (Figure 1). This trap design was made of plastic at the Italian laboratory and was similar in shape and size to the "Estron" trap which had been used earlier [32, 47]. This trap design was modified in order to prevent the adults from escaping. The traps were developed and modified until YATLOR funnel traps were made by modifying the bottom part like YATLOR prototype and an upper part resembling the Bottle trap [36]. Each trap has different performance in capturing adult beetles. With TAL, YATLOR designs, the beetles could get into the traps by crawling in. They do not need to fly into the traps. Conversely, the BOTTLE and VARb traps will need the beetles to fly in (flying traps). The craw in traps (TAL and YATLOR traps) was proved to be much less effective in catching the flying species. Also, the BOTTLE and VARb traps were shown that they were not suitable for catching *Agriotes brevis* and *A. obscurus* [36].

Ivezić et al. [48] conducted study on the implementation of pheromone traps in detecting click beetles population level in East Croatia. In this study, they used traps baited with pheromone composition for seven species from genus *Agriotes*. Their result was similar to Vernon and Tóth [36] in the way that VARb trap was suitable only for flying species, while YATLOR trap was suitable for crawling species. However, YATLOR funnel traps were proved to be effective in monitoring all the species [36, 48].

Evaluation of the effectiveness of the pheromone traps in different areas with different populations was also conducted. Mostly this evaluation was done in several European countries. The efficacy of the new *Agriotes* sex pheromone traps in detecting wireworm population levels was done in different European countries [49]. From this study, the individual traps were baited with lures for one of the following species: *A. lineatus*, *A.obscurus, A. sputator, A. soridus, A. illiger, A. rufipalpis, A. brevis, A. litigiosus,* and *A. ustulatus*. The researchers used bait traps and soil sampling to estimate the larval populations. Their results revealed that pheromone traps were able to detect dominant species and moreover the pheromone traps were selective enough to distinguish *A. sputator* and *A. brevis* despite the fact that these two species are systematically very close. They stated that sex pheromone traps proved to be a much more sensitive tool than soil sampling and bait traps for larvae. Moreover, all species traps were able to detect wireworm populations below those that can be detected using soil sampling and bait trapping [49]. However, some species of *Agriotes* click beetles, for example, *A. lineatus*, *A. obscurus*, and *A. sputator*, were found to response to pheromone trap differently. Hicks and Blackshaw [50] revealed that there were significant differences in recapture rate between species and release distance. Thus, the species specific pheromone traps used to monitor click beetles may not show the same equal catch of adult males for each species. If the pheromone traps are placed at 40 m minimum spacing, there will be overlapped of sampling areas for *A. lineatus* and *A. obscurus* and this also suggests that the trap interference could occur for the small space between each pheromone trap [50]. Blackshaw and Vernon [9] also demonstrated that there could be spatial temporal interference between traps that may affect the detection of spatial structure. They suggested that the optimal trap spacing for *A. obscurus* should be in the range 29–59 m apart and for *A. lineatus* it should be greater. Therefore, we can no longer assume that all pheromone traps operate with similar physical capture properties [50]. Iwanaga and Kawamura [51] reported that funnel-vane traps captured significantly more males of both *M. sakishimensis* and *M. okinawensis* than did water pan traps. The wind also plays a major role in trap catches. For example, Kawamura et al. [52] reported that on Miyako Island, on calm days, funnel-vane traps and water pan trap with a vane traps captured significantly more *M. sakishimensis* males than funnel traps and water pan traps. On windy days, funnel-van traps and water pan traps with a vane traps captured more males than funnel and water traps, but the differences were not significant. The author also reported that traps at ground level (2 cm) and

30 cm captured more males than traps at 90 cm and 150 cm above the ground.

7. Mass Trapping of Click Beetles

Using mass pheromone trapping to control male click beetles does not seem to work well in the field. Sufyan et al. [53] conducted study on effect of male mass trapping of *Agriotes* species on wireworm abundance and potato tuber damage. What they found was that male mass trapping is not a suitable approach to reduce wireworm populations in the soil. The reason for that was because the relationship between pheromone trap catches of male beetles and wireworm populations in the soil is still not clear. Therefore, a prediction of potential wireworm damage based on male trapping is not yet possible [54]. However, current pheromone traps are sensitive enough to detect low-density populations and trapping systems are able to indicate to the growers about the presence or absence of wireworm infestation [35]. Mass trapping experiments by Arakaki et al. [55] to control *Melanotus sakishimensis* Ohira with a trap density (0.57 trap per ha) close to the manufacturer standard (0.67 trap per ha) indicated the reduction of the yearly trap catches was not successful.

On the contrary, there are some encouraging results in case of mass trapping. Nagamine and Kinjo [44] reported success in mass trapping to control *Melanotus okinawensis* in the sugarcane fields in Okinawa (Japan) from 1985 to 1989. Since then, mass trapping has been conducted to control this species in various regions, with trap densities of 0.67–1 trap per ha. Despite these controls by mass trapping on several islands over a span of 10 yr, enough control effects have not been achieved. The mass trapping experiment to control *M. okinawensis* with a high trap density (10.6 traps per ha) on a small island during 6 yr, a great reduction in the yearly trap catches, and wild population were observed [56].

8. Mating Disruption for Control of Click Beetles

There seems to be only one example on mating disruption study conducted in case of wireworms. Arakaki et al. [57] conducted mating disruption experiments to control *M. okinawensis* indicating that the mean total catches obtained by monitoring traps in the sugarcane field decreased by 96.1% in 2001 from the previous year on Minami-Daito Island (Japan). The mean total trap catches in the treated area further decreased by 74.0% from 2001 until 2007 as cumulative effects. Simultaneously, the number of adults captured by hand decreased from 4.7 per sugarcane field in 2001 to 0.5 in 2007 (89.3% reduction), whereas those captured in the untreated area did not show such a decrease. The mating rates were significantly lower in the females captured in the treated area (14.3–71.4%) than those in the untreated area (96.9–100%). These results indicated that the mating disruption effectively reduced an isolated population of *M. okinawensis*. The authors also concluded that, for *M. okinawensis* by using synthetic sex pheromone, the mating disruption method may be preferable to the mass trapping method from a practical point of view.

9. Click Beetles and Trapping Protocols Applied in the Field

The pheromone trapping protocols have been established by some researchers. For example, Furlan et al. [49] conducted the experiment on evaluation of the effectiveness of the pheromone traps in different areas with different populations. The way they set up their pheromone traps was that they installed the traps in the field and each trap was separated 30 meters apart from one another. The pheromone should be replaced within the period of 4–6 weeks [49, 53]. The inspection of pheromone traps should be conducted once or twice a week [49, 53]. All specimens should be removed from the traps at each observation and retained.

10. Conclusion

Pheromones of click beetles were identified especially to be the dominant species in Europe [6, 26]. The synthetic pheromones have been used in traps and are able to detect the click beetle populations which are useful for monitoring at the field scale. However, to control click beetles by mass trapping baited with pheromones is still questionable due to difficulty in interpreting correlation between pheromone trap catches of male beetles and wireworm populations in the soil. Nevertheless, the growers can still get benefit from current pheromone traps in detecting the presence or absence of wireworm infestation in soil even with the low-density populations.

11. Future Studies

The pheromone bait compositions to attract click beetles have been optimized. However, most of the click beetle pheromone research has been conducted throughout European countries [6, 21, 28] and some parts of Canada [9]. As a result, highly effective pheromone baits are available now for all the important pest click beetle species mainly in Europe. Experiments on the uses of pheromones have been scarce so far with click beetles in the United States and Asian countries. More studies should be conducted in these parts of the world because there might be some different factors playing role in giving not exactly the same results as those in European countries, for example, European click beetle populations might not be the same as those in the United States or other Asian countries. Moreover, more studies need to be done to determine the actual range of attractiveness, the correlation between males captured and the number of females, or the correlation between adult trap catches and wireworm populations in different geographic and climatic conditions. The communication disruption system appears to be effective for the sugarcane wireworm management. Therefore, further studies on this aspect for the management of wireworms on other crops will be helpful and possibly an effective tool for managing the wireworms.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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