Integrating behavioral control with reduced area treatment approach for managing Colorado potato beetle and other insect pests of potato

PROBLEM, BACKGROUND, AND JUSTIFICATION:

Problem

Potato is one of the most important crops in the Northeastern United States. It is attacked by a number of insect pests that can completely destroy the crop in the absence of appropriate control measures. Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is the most important insect defoliator of potatoes (Weber and Ferro 1994). None of the control techniques developed against this pest during the past 135 years has provided long-term protection of potato crops (Casagrande 1987), and the beetle continues to be a major threat to potato production. High fecundity, a diverse and flexible life history, and a remarkable ability to develop insecticide resistance make Colorado potato beetle management a challenging task.

Aphids constitute another group of phytophagous insects that are important pests of potatoes in Northeastern North America. In relation to potato plants, aphids can be divided into colonizing and non-colonizing species. Potato aphid (*Macrosiphum euphorbiae* (Thomas)), buckthorn aphid (*Aphis nasturtii* Kaltenbach), and green peach aphid (*Myzus persicae* (Sulzer)) commonly colonize potato plants in Northeastern U.S. and Canada. Foxglove aphid (*Aulacorthum solani* (Kaltenbach)) is also capable of developing on potato, but it is by far less common than the other three species. Populations of potato-colonizing aphids seldom reach densities sufficient to cause noticeable crop injury by sap feeding. However, their ability to transmit plant viruses is an ominous threat to commercial potato production (Radcliffe et al. 1993). Other North American aphids do not colonize potato plants because they are unsuitable hosts for their development. However, rejection of non-host plants does not take place until aphids probe them with their mouthparts (Kennedy 1950, Swenson 1968). As a result, dispersing winged adults of non-colonizing species commonly land on potato plants, insert their stylets into plant tissue, and then leave in search of a more appropriate host. While direct damage caused by probing is negligible, probing may result in the transmission of potato virus Y (PVY) to healthy plants (Citation needed).

Unlike aphids, leafhoppers are important pests of potatoes mainly because of the direct feeding damage that they cause (Radcliffe et al. 1993). The potato leafhopper, *Empoasca fabae* Harris, is the most damaging species in the Northeastern U.S. Potato leafhopper adults overwinter only in a permanent breeding area along the Gulf Coast from southern Louisiana to northern Florida. In spring, the leafhopper population in those areas increases, and flying adults are caught in air streams and transported over the eastern U.S. and parts of southern Canada. The progeny of these migrants are often responsible for causing severe damage to Northeastern potato fields (Radcliffe et al. 1993).

Larval stages of the European corn borer, *Ostrinia nubilalis* Hübner, damage potato vines by boring into the stems, thus interfering with the movement of plant nutrients and water, and opening the entry routes for bacterial pathogens (Ferro and Boiteau 1993). European corn borer damage to potato is usually sporadic, but can be quite severe in areas of heavy infestation.

Just as in most other crops, potato growers rely mostly on synthetic chemicals to alleviate insect problems. However, over-reliance on insecticides is a dangerous and unsustainable approach. Not surprisingly, there is substantial public pressure to reduce insecticide use. This is especially true in the Northeastern region, where increasing urbanization has led to the development of a mosaic residential/agricultural landscape in formerly agricultural areas, thus commonly creating a conflict between the residential population and farmers over perceived dangers of insecticide use. On the positive side, this proximity generates marketing opportunities based on increased consumer awareness of sustainable agricultural practices. Therefore, reducing insecticide use by developing truly integrated approaches to managing potato pests is essential to the survival and development of Northeastern potato production.

Despite much talk about its benefits, integrated pest management (IPM) is still far from being universally adopted by commercial potato growers. Currently, insect pest control in potato in the Northeastern region is largely based on using the chloronicotinyl insecticide imidacloprid. The primary target of imidacloprid applications in potato is Colorado potato beetle (Dively et al. 1998, Blom et al. 2002). It also provides good control of potato-colonizing aphids, which otherwise may significantly reduce marketable yield by transmitting a number of potato viruses (Boiteau et al. 2000, Alyokhin et al. 2002). Imidacloprid is less effective against potato leafhopper, and has no activity against European corn borer. However, its high efficacy against the primary potato pests has led to its wide acceptance by potato farmers, and somewhat diminished their interest in alternative control methods.

Most potato growers apply imidacloprid (Admire®) in furrow at planting to the whole field. Essentially, such an approach meets the definition of a calendar-based application. Relatively few farmers practice even first level chemically based IPM by scouting their fields and applying foliar formulation of imidacloprid when insect populations exceed economic threshold levels (Dwyer et al. 1997). Virtually nobody practices more advanced forms of IPM on a large commercial scale.

In-furrow applications maximize plant coverage and significantly increase insecticide persistence in potato foliage. Unfortunately, their relatively high cost increases already high costs of potato production. Furthermore, whole-field systemic applications create strong selection pressure on insect populations towards developing resistance to this compound (Zhao et al. 2000, Olson et al. 2000). In addition, despite a fairly low mammalian toxicity of imidacloprid, its applications still have a significant adverse effect on the environment. Using classical willingness-to-pay survey methodology, Ziegler et al. (2002) estimated that environmental costs of applying imidacloprid to Maine potato crops may be as high as $20.96 per acre.

Thiamethoxam (Platinum®, Syngenta Crop Protection, Greensboro, North Carolina) is another neonicotinoid insecticide that is becoming increasingly popular with commercial potato growers. However, its chemistry and mode of application are very similar to that of imidacloprid. Therefore, it is likely that widespread use of this compound will result in problems similar to those caused by imidacloprid.

Reliance on a single group of closely related compounds is a dangerous case of "putting all eggs in one basket," with the fallacy of such an approach being repeatedly and expensively demonstrated throughout the history of pest control. The first cases of field Colorado potato beetle resistance to imidacloprid have already been reported (Zhao et al. 2000, Olson et al. 2000), and there is no reason to believe that it will not spread throughout presently susceptible beetle populations (Forgash 1985, Ferro 2000). Although resistance development can be delayed by using appropriate management practices, diversification of a pest management "portfolio" is still an important task facing commercial potato growers. Simple replacement of imidacloprid by some other chemical (or even a non-chemical control method) will never provide a lasting solution to pest control in potato fields. It is essential that not only do we have a variety of techniques available for suppressing pest populations, but also that these techniques are unified in a single economically optimized approach.

Despite their deep appreciation for risk-reducing properties of imidacloprid and other insecticides, commercial growers are forced to look for strategies to reduce application rates without compromising their efficiency because of the relatively high costs of these chemicals. In November 1997, 40 participants representing all segments of the potato industry gathered in Presque Isle, Maine for a workshop co-hosted by the Maine Potato Board and USDA-ARS. The panel identified as the important research priority

> *Methods to control costs of production (diseases, insects, nutrient types and application techniques, etc.) and storage. Input evaluation was considered an important avenue to address this issue. Also included are new technologies to allow new production techniques* (Corey and Honeycutt 1997).

In November 2000, a committee of growers and scientists confirmed that

> *Compared to 1997, this research is more important now* (Corey 2001).

Background

Reduced agent-area treatment (RAAT) is a pest management strategy in which the rate of insecticide is reduced from traditional levels, and untreated swaths (refuges) are alternated with treated swaths (Lockwood et al. 2002 and references therein). This approach is intended to achieve a more economically and environmentally sound pest management strategy compared to traditional uniform applications at high rates. The success of this approach depends on both conservation of naturally occurring biological control agents in the untreated swaths and the movement of insects from untreated swaths into treated swaths (Lockwood et al. 2000, 2002).

Reducing application rates within treated rows (RAAT *sensu strictu*, Lockwood et al., 2002) in a potato cropping system would violate a high dose-refuge approach to managing insecticide resistance (Follett et al. 1993, Gould et al 1993). Therefore, it may not be advisable because of the Colorado potato beetle's ability to develop resistance to virtually any compound that has ever been used against it (Forgash 1985, Ferro 2000). However, the total amount of insecticides applied at a label rate could still be reduced by treating only certain proportion of the total field area. Dively et al. (1998) compared Colorado potato beetle populations in plots of mixtures of imidacloprid-treated and untreated rows with its populations in untreated and completely treated plots. The effectiveness of imidacloprid in mixed plots was greater than the additive effect based on the proportional contribution of the treated rows, although beetle feeding in the untreated rows still resulted in significant reduction of the overall potato yield.

Dively et al. (1998) suggested perimeter spray that leaves a block of untreated rows in the middle of an imidacloprid-treated field as a more efficient approach to managing Colorado potato beetle populations. Colonization of potato crops by insect pests starts at field edges, and then progresses towards field center (Voss and Ferro 1990, Weber and Ferro 1993, Boiteau et al. 1994, DiFonzo et al. 1996). Therefore, treated rows serve as barriers to the pests colonizing potato fields. As a bonus, untreated rows also serve as a refugium for insecticide-susceptible insects. Imidacloprid resistance in the Colorado potato beetle is incompletely recessive (Zhao et al. 2000). Therefore, the progeny of resistant × susceptible crosses can be effectively killed by imidacloprid applied at the recommended rate.

Blom et al. (2002) tested the perimeter approach on one-acre field plots in Pennsylvania. In their experiments, the perimeter treatment (25% of field area) significantly reduced mean beetle densities. Comparing the perimeter to untreated fields, yields increased at a proportion that was higher than the proportion of land area treated. However, they still remained significantly lower than the whole-field treatment, leading to the authors' conclusion that refinement of border width is necessary to optimize trade-offs among yield, quality, and long-term maintenance of susceptibility.

Following the recommendation of its Research Committee, the Maine Potato Board awarded A. Alyokhin $3,000 to test the feasibility of replacing whole-field imidacloprid applications with perimeter sprays, a technology originally developed by Dively et al. (1998). An additional $6,000 was awarded from the same source following the presentation of preliminary results to continue this project in 2002. Studies conducted on the territory of the Aroostook Research Farm and commercial potato farms for the past several years demonstrated that perimeter (conservative approach, treating 80% of the whole field) sprays provide an excellent protection of potato crops from Colorado potato beetle and aphid infestation (Figs. 1 and 2). In the present proposal, we suggest advancing the reduced-area treatment approach by integrating it with behavioral control to further decrease the amount of insecticides necessary for successful pest control.

Manipulation of chemically mediated behaviors provides a valuable tool for suppressing populations of pest insects that can be easily integrated with a number of other approaches. Several synthetic kairomone blends, based on the volatiles produced by potato plants, have been recently demonstrated to be attractive to both adult and larval stages of the Colorado potato beetle (Dickens 1999, 2000, 2002). The most promising blend comprises three components [(*Z*)-3-hexenyl acetate, (±)-linalool, and methyl salicylate], and is currently commercially available.

Kairomones can be used for attracting beetles to insecticide-treated areas within reduced area treatment systems, thus increasing their exposure to toxins and reducing the amount of insecticides necessary for successful beetle control. Kairomone-induced population re-arrangement in such a system will also enhance gene flow between a susceptible beetle population residing in the untreated portion of the field, and a resistant population that might be surviving on plants treated with insecticides. Substantial gene flow, in turn, is required for successful implementation of the high dose-refugia strategy for managing insecticide resistance (Tabashnik 1986, Alyokhin et al. 1999, Zhao et al. 2000).

Recent greenhouse and small-plot field studies (Martel, Alford, and Dickens submitted) have clearly demonstrated a noticeable impact of kairomones on beetle behavior. In greenhouse arenas, kairomone-treated plants attracted more than three times as many adult beetles as untreated plants (Fig. 3). Each arena consisted of a 1.22 m x 0.61 m mesh-enclosed cage. Two plastic plant pot rims (diameter 20.32 cm), separated by 25.4 cm, lay flush with the cage floor, such that field-collected soil concealed both the floor and pot interior to simulate field conditions. Plants were selected for each arena on the basis of similar age (six weeks old), height (≈30.48 cm), and foliage breadth (≈35.56 cm). Aluminum flashing (1.52 m x 25.4 cm) placed in elliptical fashion around the floor perimeter precluded insects from accessing the mesh walls, keeping all insects within the arena. At the beginning of each trial, one of the plants in each arena was treated with kairomones.

Similarly, significantly higher beetle densities were observed within treated potato field plots than within untreated potato plots (Fig. 4). However, large-scale testing under farm field conditions still remains to be done. Also, little is known about possible effects of these compounds on other insects inhabiting potato crops, including both pests and natural enemies.

There are two general ways in which a kairomone-enhanced reduced area treatment approach can be implemented within potato fields. First, kairomones may be used to enhance the interceptive power of insecticide-treated field perimeters. If plants treated by an insecticide/kairomone combination are highly attractive to colonizing Colorado potato beetles, their relatively narrow swath should represent a sufficient barrier to protect the entire field from beetle damage. Second, kairomones may be used to reduce the amount of foliar insecticides applied when beetle populations reach economic threshold levels. In such a system, adequate protection may be achieved by treating selected rows instead of the whole fields. Kairomones applied to the treated plants would draw beetles from the untreated plants, thus preventing their subsequent defoliation. Although in a totally different system (grasshoppers damaging Midwestern pastureland), this technique proved to be very successful in the studies by Lockwood et al. (2000, 2001).

Whatever the mode of their application is, plant kairomones show a great promise to become a part of a true IPM system for potato crops. However, several issues still need to be addressed before a wide-scale commercialization effort.

First, the only insecticide that has been formulated together with plant kairomones as a part of attracticide blend and tested in small-plot trials is permethrin (Alford, Martel, and Dickens unpublished). This is a fairly broad-spectrum insecticide that is toxic to many natural enemies. Furthermore, it is often not very effective against the Colorado potato beetle because of its low persistence and resistance development within beetle populations (Forgash et al. 1985). In addition to widely used neonicotinoids, several low-risk selective insecticides are currently commercially available from major chemical companies. Spinosad (SpinTor®, Dow

AgroSciences, Indianapolis, Indiana) is an aerobic fermentation product of the soil actinomycete *Saccharopolyspora spinosa*. It is highly effective against the Colorado potato beetle and European corn borer, while having a low toxicity for non-target organisms, including most beneficial arthropods found in potato fields. In the near future, organic formulations of this compound are expected to appear on the market. Pymetrozine (Fulfill®, Syngenta Crop Protection, Greensboro, North Carolina) is a stylet inhibitor used against aphids, a group of pests that are not affected by Spinosad. It also has negligibly low effect on non-target organisms. These chemicals have a great potential as components of an environmentally friendly IPM system. However, they are seldom used by commercial growers, largely because of their high cost. Combining low-risk insecticides with attractants and integrating them into the reduced area treatment approach may help reduce the amount of chemicals necessary to achieve economically efficient pest control, thus making them more economically acceptable to commercial growers. As a part of the proposed project, we plan to screen a number of different insecticides and their combinations in an attempt to select the most efficient component for an attracticidal blend.

Second, although kairomones proved to be a promising tool under laboratory and greenhouse conditions, the situation in the field may be more complicated. Potential problems with kairomones include the following:

1. In spite of being attractive in the lab, kairomones may not have enough power to induce an economically significant population re-arrangement in a commercial-size field. Preliminary data collected during this season show that it is probably not the case (Figs. 3 and 4), but additional investigations are required before drawing definite conclusions.

2. Kairomones that have been demonstrated to attract Colorado potato beetle are pretty general plant volatiles (Dickens 1999, 2000, 2002). Therefore, potentially they may also attract leafhoppers or European corn borers to the treated areas (Todd et al. 1990, Lupoli et al. 1990, Udayagiri and Mason 1995). Neither of those pests is killed by insecticides that are specific to Colorado potato beetle and/or aphids.

3. Similarly, they may attract aphids (Isaacs et al. 1993, Hori 1999) that, in turn, may transmit potato viruses.

4. Attracticides may attract more Colorado potato beetles than they kill. This is unlikely if kairomones are applied with systemic insecticides, but possible if they are applied with foliar insecticides with low residual activity.

5. Alternatively, kairomones might have too low a residual activity, requiring costly repeated applications to attract a significant number of beetles to the treated areas.

6. Kairomones may interfere with natural enemies. Plant volatiles play a significant role in host foraging behavior of a number of economically important biological control agents, including those attacking aphids, Colorado potato beetles, leafhoppers, and European corn borers (Udayagiri and Jones 1995, Du et al. 1996, Honda and Walker 1996, Dickens 1999). Conservation of the existing natural enemies commonly helps to suppress pest populations within potato fields. Aphid populations often reach outbreak densities

following applications of broad-spectrum insecticides that kill their natural enemies (Radcliffe et al. 1993). Applying plant-derived Colorado potato beetle attractants to potato crops may cause a similar effect by interfering with natural enemy behavior. On the contrary, it may attract additional natural enemies into the treated areas. If the latter is true, the selectivity of insecticides used in combination with attractants may become particularly important.

By carrying out the proposed project, we are planning to investigate both positive and negative aspects of kairomone deployment.

Finally, in addition to the Colorado potato beetle, whole-field applications of imidacloprid or thiamethoxam also control potato-colonizing aphids, and, to a certain extent, potato leafhoppers. Therefore, if kairomones make using the reduced area treatment approach effective against the Colorado potato beetles, but not other insect pests of potato, it might be still unacceptable for commercial growers. An integrated approach that we propose will address the issue of controlling those pests, and incorporate the costs of their suppression in the overall cost-benefit analysis.

Justification

Potato provides an excellent system for implementation of a comprehensive IPM program. First, a considerable amount of information is available on basic biology of major potato pests. Although we are still far from a complete understanding of all the details, such knowledge can provide a foundation for making educated pest management decisions. Second, economic thresholds have been developed for most potato pests (e.g., Dwyer et al. 1997), and Cooperative Extension personnel already conduct an extensive monitoring program at commercial potato farms. Thirdly, a number of novel low-risk insecticides that are active against potato pests recently appeared on the market. Finally, newly discovered Colorado potato beetle attractants potentially open the way to enhance insecticide efficiency by manipulating pest behavior (Dickens 1999, 2000, 2002, Dickens et al. 2002).

Implementation of the reduced area treatment technology is very simple and does not require any special skills or major modifications in the existing crop management practices. All that is required is to place flags in certain areas of the field and to shut down the sprayer each time the tractor enters the flagged area. Plant kairomones attractive to the Colorado potato beetle can be easily synthesized, are relatively inexpensive, and are currently available from a commercial crop protection supply company. Spraying them in the field does not require any specialized equipment.

All in all, we already have an array of user-friendly, environmentally sound, and biorational tools in our disposal. Using them as parts of a comprehensive pest management approach will be of great benefit to all parties involved in (or affected by) potato production in Northeast. Our project will directly address all four base priorities of the Northeastern IPM Grant Program as follows:

Environmental stewardship and risk management: If successful, our project will significantly reduce the amount of insecticides applied to potato crops while reducing the probability of insecticide resistance development in Colorado potato beetle populations.

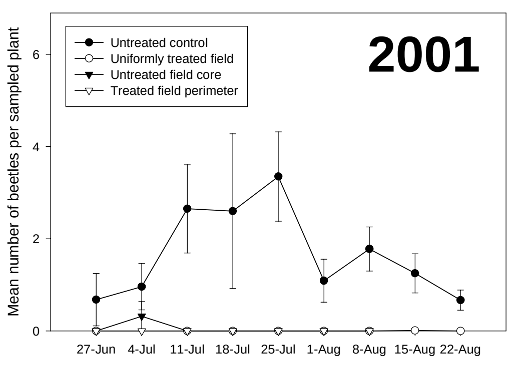
Importance and value of the crop or cropping system to the Region: With 113,600 acres harvested in 2001, potato remains the most important horticultural crop in the Northeastern region (USDA-NASS 2002).

Importance of the pest or pest complex to the crop or cropping system: Colorado potato beetle is the most important insect defoliator of potatoes in most potato-growing areas in the nation.

Likelihood of implementation: Implementation of this technology is fairly easy and does not require any special skills, knowledge, or equipment. All necessary materials are already commercially available. Growers show considerable interest in reducing treated areas for economic reasons, as evidenced by their willingness to fund our preliminary investigations of this subject.

OBJECTIVES:

1. Develop economically feasible "attracticide" blends combining Colorado potato beetle plant attractants with low-risk insecticides.
2. Determine possible effects of these attracticides on non-target arthropods, such as other potato pests and beneficial natural enemies.
3. Evaluate efficiency and economic feasibility of reduced area treatment approach combined with attracticide blends.



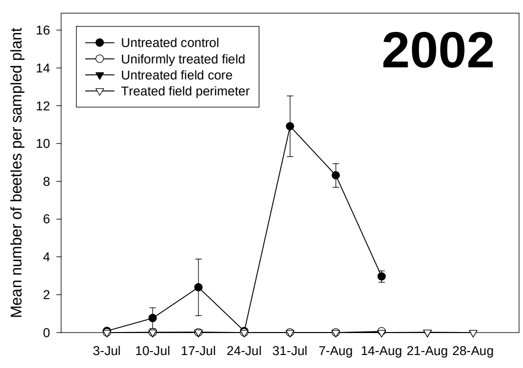


Fig. 1. Effect of border sprays on Colorado potato beetle abundance (larvae and adults combined). Beetle life stages were sampled weekly on 25 randomly selected plants within each of the four treatments. Field size varied from 1 to 10 acres.

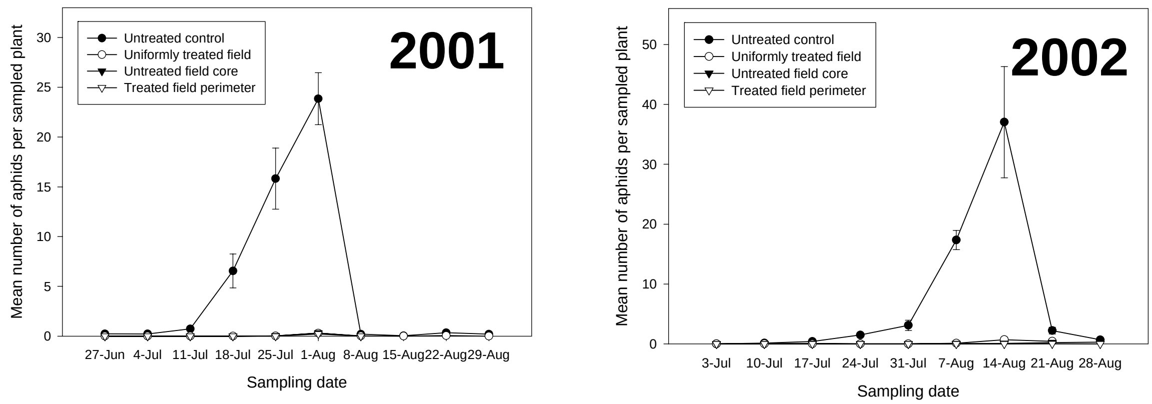


Fig. 2. Effect of border sprays on aphid abundance (*Macrosiphum euphorbiae*, *Aphis nasturtii*, and *Myzus persicae* combined). Aphids were sampled weekly on one top, one middle, and one bottom leaf on 25 randomly selected plants within each of the four treatments. Field size varied from 1 to 10 acres.

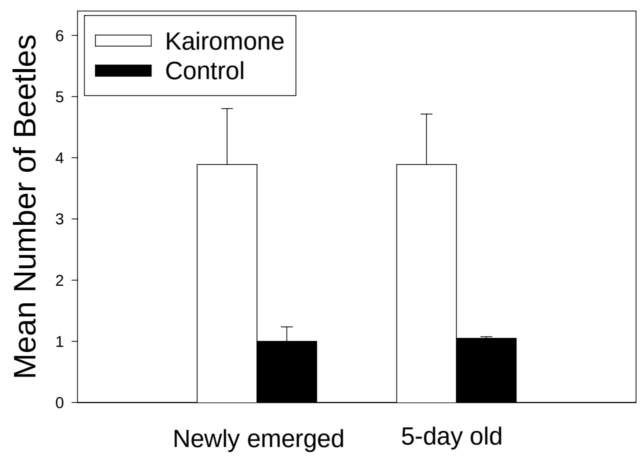


Fig. 3. Attraction of adult Colorado potato beetles to kairomone-treated plants in greenhouse arenas.

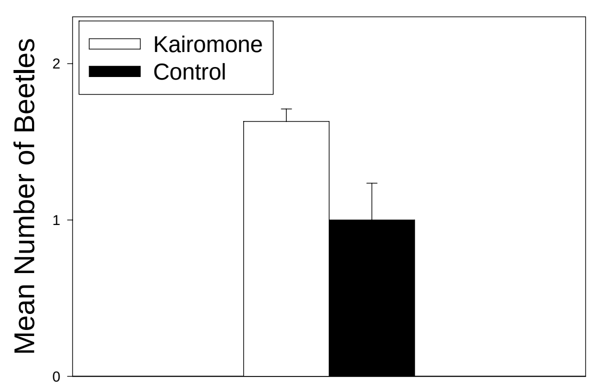


Fig. 4. Attraction of adult Colorado potato beetles to kairomone-treated plants in the field.