Field evaluation of pneumatic control of Colorado potato beetle

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Lacasse, B., Laguë, C., Khelifi, M. and Roy, P.-M. 1998. **Field evaluation of pneumatic control of Colorado potato beetle**. Can. Agric. Eng. 40:273-280. A front-mounted prototype designed to pneumatically remove Colorado Potato Beetles (CPB), *Leptinotarsa decemlineata* (Say), from potato plants was tested in the field. Effects of different combinations of airflow velocities, airflow widths, and travel speeds were investigated. Results showed that dislodging and capture of CPB were better for adults and large larvae (L3 and L4). On the other hand, neither the airflow width and velocity nor the travel speed significantly affected the dislodging and collection of small larvae (L1 and L2). Field trials on the removal of larvae under the effect of different travel speeds showed that collection of L3-L4 larvae was improved at reduced travel speeds. Operating in the field at a travel speed of 6 km/h while maintaining a good collection efficacy does appear possible. This study demonstrates the potential of pneumatic control of CPB adults and L3-L4 larvae. **Keywords**: Colorado potato beetle, insect control, pneumatic, potato, prototype.

Un prototype d'appareil de contrôle pneumatique du doryphore de la pomme de terre, *Leptinotarsa decemlineata* (Say), a été évalué au champ. Les effets de différentes combinaisons de vitesses d'air, de largeurs de buses et de vitesses d'avancement ont été étudiés. Les résultats ont montré que le décrochage et la collecte étaient plus élevés pour les adultes et les grosses larves (L3 et L4). Par ailleurs, ni la vitesse d'air, la largeur de buse ou la vitesse d'avancement n'ont significativement influencé le décrochage et la collecte des petites larves (L1 et L2). Les essais au champ portant sur les vitesses d'avancement du prototype ont montré que plus le prototype se déplaçait lentement, meilleure était l'efficacité de capture des grosses larves. Il est toutefois apparu possible d'opérer à une vitesse d'environ 6 km/h tout en maintenant une bonne efficacité de collecte. Cette étude démontre le potentiel du contrôle pneumatique des adultes et des grosses larves de doryphore. **Mots clés**: doryphore de la pomme de terre, contrôle des insectes, pneumatique, pomme de terre, prototype.

INTRODUCTION

The Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata* (Say), is the most important insect pest for potato crops in Eastern North America (Hare 1990). For many CPB populations, heavy reliance on chemical pesticides to control this insect has resulted in the development of resistance to most types of insecticides and this with an increasing rapidity (Forgash 1985). Since Aldicarb has been banned in many areas because of environmental concerns, other insecticides are currently used at higher dosages, thus increasing production costs. The expected development of resistance to new insecticides (Hare 1990), the increasing development costs of these chemical products (Metcalf 1980), and the growing demand for potatoes free of pesticide residues clearly demonstrate the need for other reliable and economical means to control CPB.

A relatively old concept that regained some popularity in recent years is the use of vacuum machines. Such machines were extensively used in strawberry, lettuce, and carrot fields in California (Boiteau et al. 1992). As part of an integrated pest management program, this technology could substantially reduce the environmental impacts of insecticide applications and the need for farmers to handle toxic products. At least two machines using airflows to control CPB have been commercially available: the Beetle Eater (Bugs Unlimited Inc., MA and Thomas Equipment Ltd., NB) and the Bio-Collector (Bio-Land Technick, Mühlhausen, Germany). Limited performance of these machines has, however, been reported (Boiteau et al. 1992). Also, only limited data such as holding capabilities of CPB (Misener and Boiteau 1993a), terminal velocity of falling CPB in the air (Misener and Boiteau 1993b), resistance of potato plants and CPB to airstreams (Khelifi et al. 1995a, 1995b), and required plant vibrations to dislodge CPB (Boiteau and Misener 1996) are available to optimize the design and use of vacuum or other types of pneumatic systems for the control of pest insects. The particular work reported herein presents such basic data along with a description of the various phenomena that occur for the specific case of pneumatic control of CPB.

BACKGROUND

It is important to define the insect collection efficacy in order to well understand the process of pneumatic control of insect pests. The collection efficacy is the result of two effects. First, there is the dislodging efficacy, which is the percentage of insects removed from the plants under the effects of airflow. Secondly, the capture efficacy that represents the ratio of dislodged insects that are picked up by the collecting device to the total number that were pneumatically dislodged. The insect collection efficacy can thus be expressed as:

$$\eta_{coll} = \eta_{disl} \times \eta_{capt} \tag{1}$$

where:

η_{coll} = insect collection efficacy (ratio between number of insects* collected by pneumatic system and total number of insects initially present on the plants),

η_{disl} = insect dislodging efficacy (ratio between number of insects dislodged from plants by pneumatic system and total number of insects initially present on the plants), and

η_{capt} = insect capture efficacy (ratio between number of insects collected by pneumatic system and number of insects dislodged from the plants).

*The number of insects may be expressed as a population density per plant or per unit area.

Harcourt (1971) reported that large CPB larvae (third, L3, and fourth, L4, instars) dislodged from the plants by rainfall can usually climb back onto potato plants. As a result, insect collection efficacy is a measure of the overall efficacy of pneumatic control for such larvae, and also for CPB adults that exhibit even better mobility. For small CPB larvae, one must account for the proportion of insects that was unable to climb back on the potato plants in order to determine the overall efficacy of the process defined as:

$$\eta_{ov} = \eta_{coll} + \left[\eta_{disl}(1-\eta_{capt}) \times G/D\right] \qquad (2)$$

where:

η_{ov} = overall efficacy of pneumatic control, and

G/D = ratio between dislodged insects unable to climb back on the plants and total number of insects dislodged from the plants by pneumatic system.

Unfortunately, no data regarding the proportion of small larvae unable to climb back onto the potato plants after being dislodged under either wet or dry conditions are available in the literature. Therefore, the ratio G/D was considered equal to zero in this study.

Boiteau et al. (1992) evaluated the Beetle Eater, a vacuum CPB collector developed in Massachusetts. This particular machine blows a pair of ascending airstreams on each side of the rows and vacuums the top of the plants to collect the dislodged insects. For an average travel speed of 4 km/h, CPB counts were made before and after single passes of the Beetle Eater in microplots of potato plants (cv. Russet Burbank, 510 mm tall) and a canopy cover of 3 on a 1 to 4 scale. No airflow velocity measurements were presented by the authors. Boiteau et al. (1992) concluded that this particular machine would yield maximum efficacy when targeted at the control of colonizing CPB adults and also young larvae that both drop less readily from the potato plants.

Duchesne and Jean (Personal communication. Service de Phytotechnie, Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec, QC) experimented with a German-designed machine (Bio-Collector) for pneumatic control of CPB over a 3-year period in both commercial fields and experimental plots. The Bio-Collector blows two opposite and offset horizontal airstreams across the plant rows to dislodge the insects and collects them into floating trays. In general, the control efficacy tended to be better for low CPB population densities but remained very variable. No airflow velocity data for the pneumatic system were, however, reported by the authors.

deVries (1987) conducted limited field trials on the pneumatic control of CPB adults with two basic prototypes. deVries (1987) used a horizontal airflow that created an air curtain directed across the potato plant rows. A catching device was placed on the opposite side of the row. For airflow velocities in the 15 to 30 m/s range, a test made on a sample of 47 CPB adults showed a dislodging rate of 77%. However, the collection efficacy remained low. deVries (1987) concluded that the problem was to capture the dislodged CPB adults and that high collection efficacies could be obtained with an improved collecting device. According to deVries (1987), high air velocity is needed more for transporting the CPB adults than for dislodging them. A CPB adult often easily releases *its grip*, but if for some reason it firmly grabs the plant, it will be difficult to dislodge.

Field operation of the pneumatic system

The major drawback of many mechanical control means of pest insects is the inaccessibility to fields when the plants become too voluminous. For potatoes, the impact of defoliation on yields increases until the full bloom stage and decreases afterward (Hare 1980; Shields and Wyman 1984). To rely on only pneumatic systems to control CPB over the length of the growing season, it is therefore necessary to extend the operating period of such pneumatic systems in order to reach that critical stage. It may be preferable to grow potato varieties presenting a more erect shape and use narrow tires on the machines. Devices aimed at carefully lifting up and pushing aside potato plant stems and leaves lying in the interrows in front of the machine wheels may also be required to minimize plant damage by the equipment.

Environmental factors

Climatic conditions may also influence the efficacy of pneumatic insect control. In his experiment on thermoregulation, May (1981) showed that CPB adults can move on the plants in order to modify their body temperature. CPB adults can be found in higher proportions on the upper surface of the potato plants canopy when ambient temperature is around 25°C. They tend to move in the upper third of the plants at higher temperatures. Even if this appeared to be less evident for CPB large larvae, they also tended to stay more often on the upper surfaces of the plants or in their outer layers where they are more exposed to sunlight. Also, the feeding rate of the CPB increases with body temperature. For the first instar larvae, the spatial distribution is more related to the oviposition sites as these larvae stay near the egg clusters (Boiteau and Le Blanc 1992). Dispersal becomes significant only when the larvae reach the second instar.

Dislodging of CPB adults and large larvae could, therefore, be more efficient at high temperatures. This could lead to a reasonable increase in the dislodging and collection efficacies, thus resulting in a higher capture efficacy. Since the effects of weather on the efficacy of pneumatic control of CPB are still not verified, treatments should be carried out under similar conditions to reduce the eventual possible variability when analyzing the data. Complete block (time) experimental designs are therefore suggested.

Economic considerations

Economic interest for pneumatic control of CPB will arise both from satisfactory insect control efficacy and low energy requirements to cover as many rows as possible in a single pass of the machine. For this purpose, an optimal pneumatic control system should achieve sufficient insect control at high

Table I. Dates of experiments and mean dimensions of potato plants.

Experiment	Block	Treatment date (dd/mm)	Mean dimensions of potato plants	
			Height (mm)	Width (mm)
Adults: air jet width and velocity	1 & 2	30/06	254	330
	3 & 4	04/07	254	330
Larvae: air jet width and velocity	1 & 2	07/07	460	510
	3	08/07	460	510
	4	12/07	460	510
Larvae: travel speed	1 - 4	14/07	510	560

operating speeds and minimum airflow velocity. Undesirable effects such as the removal of natural predators, the spread of viruses and other diseases, and the stressing of potato plants are possible and will have to be investigated in the future.

OBJECTIVES

The general objective of this study was to identify combinations of pneumatic factors resulting in both low energy requirements and satisfactory collection efficacy of CPB adults and larvae. The specific objectives were: (1) to evaluate the effects of airflow width and velocity and travel speed on the dislodging and collection of CPB adults and larvae; (2) to determine the energy requirement of a prototype machine for pneumatic control of CPB.

MATERIALS and METHODS

Experimental site

All field experiments were conducted at the Joseph-Rhéaume Research Farm of Université Laval located in Sainte-Croix on the south shore of the St.-Lawrence River, 50 km upstream from Quebec City. Two sets of experimental plots, each 12 by 68 m, were seeded on May 20, 1994, with potato tubers (cv. Kennebec) placed at 250 mm intervals along rows spaced 910 mm apart. Hilling of the young plants was completed on June 23, 1994. The plots were chemically treated for weeds and mildew using mainly metrobromuron and metalazyl-mancozebe, respectively. Dates of experiments and dimensions of plants are summarized in Table I.

Experimental prototype

A prototype machine for pneumatic control of CPB was developed at the Department of Soil Science and Agri-Food Engineering of Université Laval during the winter of 1994 (Fig. 1). It is a single row front-mounted machine that can be operated by any row crop farm tractor. It consists of a blowing unit that can generate horizontal airstreams coupled to an insect collecting device placed on the opposite side of the row. Possible adjustments included airflow width (25.4 or 50.8 mm) and velocity (0 to 50 m/s) at the outlet of the blowing nozzle. Nozzle height was set at 457 mm to fully expose the potato plants to the airstream. The bottom of the blowing unit was allowed to follow the ground surface irregularities and thus to remain at the same level relative to the top of the hills on which potato plants were growing. The axial multi-blade fan of the blowing unit was driven by a hydraulic motor through a gearbox. A PTO-operated hydraulic pump supplied oil to the motor from a separate reservoir.

Calibration

Airflow velocity calibration was made with a Pitot tube connected to a differential pressure transducer (Model PX164-010D5V, Omega Engineering Inc., Stamford, CT) having a range of 0 to 250 mm of H_2O and a precision of ± 1.25% over the full scale output. The calibration was also checked with a 2% precision telescopic anemometer (Solomat Instrumentation

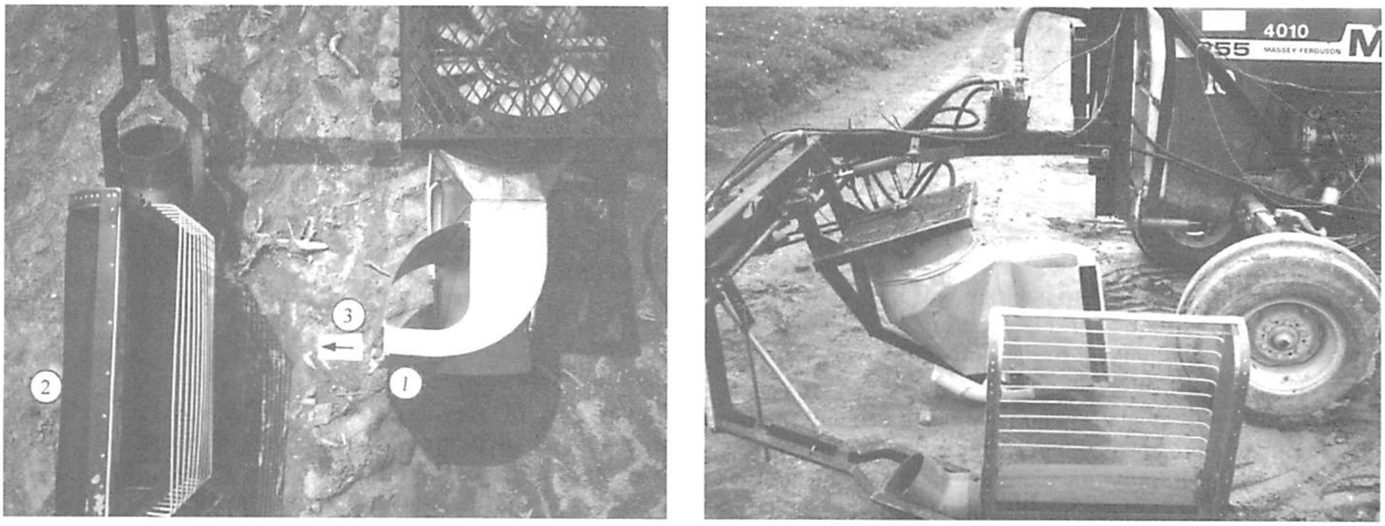

Fig. 1. Prototype machine: (left) top view; (right) side view; (1) blowing unit; (2) collecting device; (3) airflow.

Division, Norwalk, CT). The power required to drive the blowing unit was measured using a torque sensor (Model 1804-500, Eaton Corp., Troy, MI) mounted on the motor shaft. The shaft speed was sensed by a logic magnetic pickup (Model LMPC, Red Lion Controls, York, PA) targeted onto a thirty-tooth gear fixed on the gearbox shaft. The signal from the magnetic pickup was sent to a multimeter (Model DM27XL, Beckman Industrial Corp., San Diego, CA).

Experimental design and procedure

Three field experiments were conducted during the summer of 1994. The first two dealt with the effects of different airflow velocities (35, 40, 45, and 50 m/s) and blowing nozzle widths (25.4 and 50.8 mm) on the dislodging and collection of CPB adults and larvae. Horizontal airstreams directed across potato plant rows were used for this purpose. Travel speed was set at 6 km/h for both experiments. In the third experiment, a particular combination of airflow velocity (45 m/s) and width (50.8 mm) was selected to investigate the effects of travel speeds (4, 6, and 8 km/h) on the dislodging and collection of CPB adults and larvae. Single and multifactorial experiments were conducted in complete randomized blocks to test the effects of the above mentioned factors. The first two experiments were replicated four times whereas the third experiment was replicated five times. To avoid any possible variations in the behaviour or the distribution of the CPB on the plants, all factor combinations were tested during a short period of time. Tests were carried out on adults, two weeks after emergence, and on the first generation of larvae.

Row sections were used as the experimental units. These sections were selected at the beginning of the testing session (in the morning). The order of the treatments and the assignment of the experimental units were then randomized within the sections. Depending upon the density of CPB populations, the size of the experimental units (i.e. row section length) was set to seven plants for the tests on CPB adults. For the larvae, one plant was used for testing the effects of airflow velocity and width (second experiment), and two plants were used for testing the effects of travel speed (third experiment). The selection criteria were sufficient CPB populations, similar plant size, and low plant defoliation. For the CPB adult tests, 20 beetles per experimental unit were allowed to settle on the plants at least two hours before conducting the experiments.

To insure that all counted beetles came exclusively from the experimental units, potato plants located two meters before and one meter after the row sections used as experimental units were removed while the plants situated on each side of the experimental units were laid down. Soil was slightly tapped around the experimental units to facilitate the counting of the small larvae that dropped on the ground. The few beetles present on the ground surface before conducting the experiments were removed to minimize the variability in dislodging and collection data.

CPB adults present on the potato plants were counted before and after the treatments, along with those captured in the collecting device. In previous experiments it was difficult to count the CPB larvae, especially the small ones, without disturbing the plants. This often resulted in a misleading initial number of insects present on the plants. For this reason, CPB larvae were only counted after the treatments, adding those collected by the pneumatic system, dropped to the ground, and left on the plants. This provided a good estimate of the initial number of CPB larvae on the plants prior to the passage of the pneumatic system. Counted larvae were sorted according to their origin, i.e. collected, dropped to the ground (on the hills or in the interrow alleys), and left on the plants. All CPB larvae were brought back to the laboratory where they were frozen. After completion of the field experiments, these larvae were sorted with a magnifying glass according to the width of their heads (0.6, 1.0, 1.6, and 2.3 mm) in order to identify the four instars (Boiteau and Le Blanc 1992).

From the collected data, total larvae, efficacies, and distribution percentages were calculated as:

$$DISL = 100 \times \eta_{disl} = 100 \times \frac{NHILL + NALLEY + NCOLL}{NPLANT + NHILL + NALLEY + NCOLL} \quad (3)$$

$$COLL = 100 \times \eta_{coll} = 100 \times \frac{NCOLL}{NPLANT + NHILL + NALLEY + NCOLL} \quad (4)$$

$$CAPT = 100 \times \eta_{capt} = 100 \times \frac{NCOLL}{NDISL} \quad (5)$$

$$HILL = 100 \times \frac{NHILL}{NDISL} \quad (6)$$

$$ALLEY = 100 \times \frac{NALLEY}{NDISL} \quad (7)$$

where:

DISL = dislodging efficacy (insects dislodged from the plants by machine) (%),
COLL = collection efficacy (insects collected by catching device) (%),
CAPT = capture efficacy (dislodged insects collected by catching device) (%),
HILL = dislodged insects that dropped on hill (%),
ALLEY = dislodged insects that dropped on alley (%),
NHILL = number of dislodged insects dropped on hill,
NALLEY = number of dislodged insects dropped on alley,
NCOLL = number of insects collected by catching device,
NPLANT = number of insects left on the plants, and
NDISL = number of insects dislodged from the plants (NHILL + NALLEY + NCOLL).

Data analysis

An analysis of variance using the General Linear Model procedure (SAS 1988) was performed on the data at the 5% level of significance. Significant factors were further analyzed using linear and quadratic contrasts. In addition, the spatial distribution of the dislodged CPB larvae was investigated.

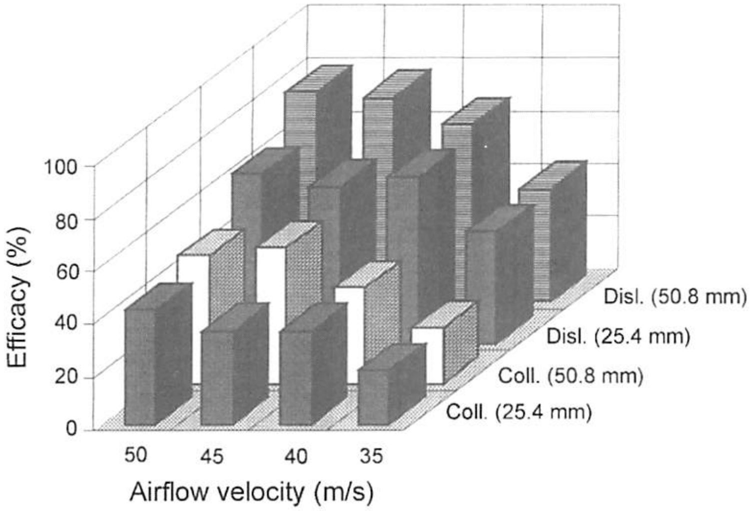

Fig. 2. Effects of airflow velocity and width on the dislodging (Disl.) and collection (Coll.) of CPB L3 larvae.

RESULTS and DISCUSSION

Effects of airflow velocity and width on CPB adults

High airflow velocities didn't significantly improve the dislodging and collection of CPB adults. Dislodging and collection efficacies averaged 61 ± 16% and 54 ± 20%, respectively, for all treatments yielding a capture efficacy of 88 ± 24%. The lower dislodging efficacy observed in this study, as compared to previous laboratory tests (Lacasse et al. 1993), could be explained by the higher foliage density of field-grown potato plants. In such conditions, more CPB adults could be shielded from airstreams by plant leaves and stems. Also, the narrower airflow width (50.8 mm) might have had an effect as its influence may have dissipated too rapidly through the crop foliage. Future research work on CPB adults should therefore concentrate on dislodging and related stimulation factors. Reducing travel speed, using a wider blowing unit outlet along with other efficient mechanical means for dislodging CPB such as a shaking system could be considered.

Effects of airflow velocity and width on CPB larvae

The average number of larvae per experimental unit were 12.2 ± 9.1, 23.9 ± 13.4, 26.4 ± 13.4, and 13.4 ± 6.5 for L1 to L4 larval instars, respectively. For all instars, the spatial distribution (collected, hill, alley) of the dislodged larvae was not significantly affected by airflow velocity and width. Also, no significant interactions between these two factors were found. Results related to dislodging and collection of each CPB larval instar are presented below.

First instar (L1) The analysis of the results revealed that airflow velocity and width did not significantly affect the dislodging and collection of CPB. Also, no interaction between these two factors was found to be significant. Average dislodging and collection efficacies for all treatments were respectively 42 ± 25% and 24 ± 24%. This was not surprising since L1 larvae are very small, almost motionless, and usually located inside a dense foliage underside the plant leaves. Consequently, it is very difficult to remove them from potato plants.

Second instar (L2) Average dislodging, collection, and capture efficacies were respectively 45 ± 18%, 24 ± 17%, and 47 ± 25%. The effects of the different treatments were also not significant at the 5% level but higher airflow velocity tended to improve both insect dislodging and collection. These results were also expected because L2 larvae are not very mobile and behave like L1 larvae.

Third instar (L3) Average capture efficacy was 58 ± 15% and proportions of L3 larvae found on the hill and the alley were respectively 18 ± 14% and 24 ± 15%. Airflow velocity linearly increased dislodging ($p = 0.0008$) and collection ($p = 0.0007$) efficacies and larger widths improved dislodging ($p = 0.045$) (Fig. 2).

Fourth instar (L4) Average capture efficacy was 61 ± 18% while the proportions of dislodged L4 larvae found on the hill and in the alley were respectively 15 ± 15% and 24 ± 16%. A larger airflow width significantly improved dislodging ($p = 0.026$), especially for low airstream velocities (Fig. 3).

At an airflow velocity of 50 m/s, much potato plant debris was found in the collecting unit. This suggests that some damage was caused to the crop by the pneumatic system at high airstream velocities.

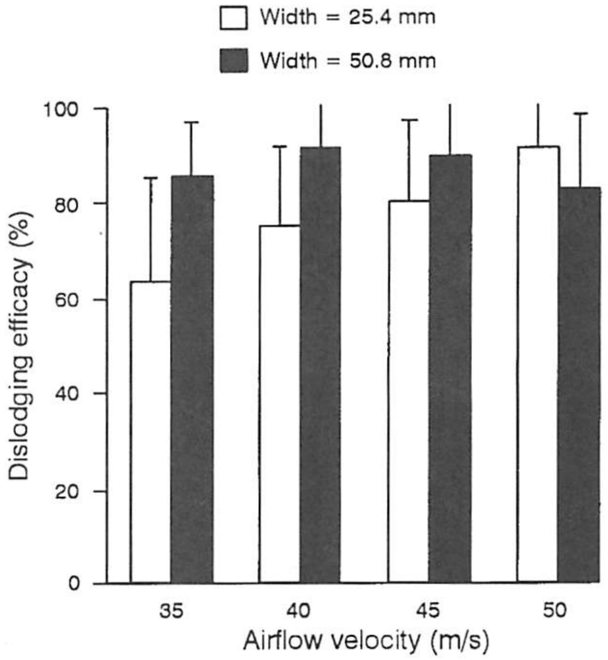

Fig. 3. Effects of airflow velocity and width on the dislodging of CPB L4 larvae (standard deviation is shown with the means).

Effects of travel speed on CPB larvae

First instar (L1) Missing data and small sample sizes prevented any statistical analysis. Out of the 105 L1 larvae encountered, 34% were dislodged and 17% collected by the collecting device.

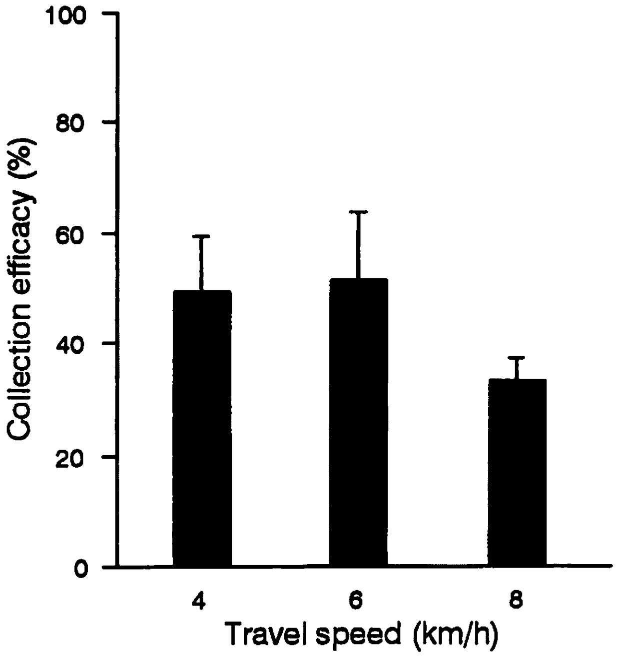

Fig. 4. Effect of travel speed on the collection of CPB L3 larvae (standard deviation is shown with the means).

Second instar (L2) Average dislodging, collection, and capture efficacies were respectively 52 ± 18%, 33 ± 18%, and 62 ± 26%. The travel speed did not significantly affect the dislodging and collection of L2 larvae. This also proves that it is very difficult to remove small larvae from the foliage.

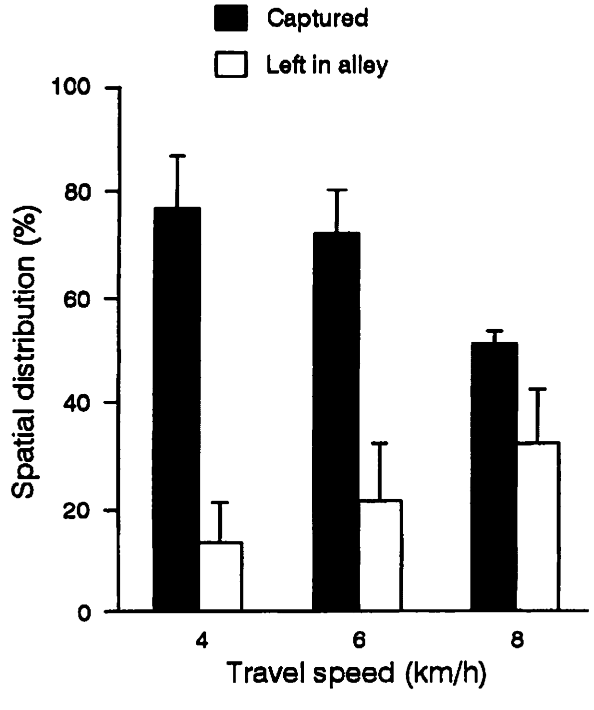

Fig. 5. Effect of travel speed on the spatial distribution of CPB L3 larvae (standard deviation is shown with the means).

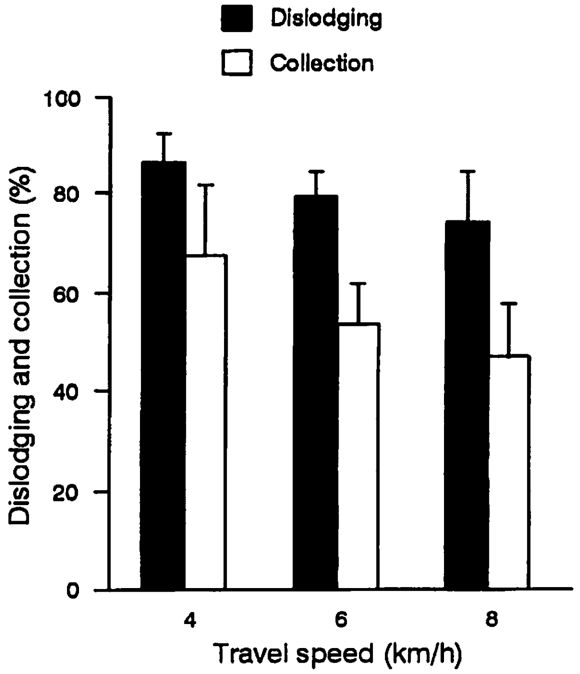

Fig. 6. Effects of travel speed on the dislodging and collection of CPB L4 larvae (standard deviation is shown with the means).

Third instar (L3) The significant effects of increasing travel speeds were: a quadratic reduction of the collection efficacy ($p = 0.006$), a linear reduction of the capture efficacy ($p = 0.0007$), and a linear increase of the proportion of dislodged insects that did drop in the alley before reaching the collecting device ($p = 0.03$) (Figs. 4 and 5). On the other hand, travel speed did not significantly affect the dislodging efficacy. The block effect (time) was only significant for collection efficacy, but no explanation can be given.

Fourth instar (L4) Higher travel speeds resulted in a significant decrease of insect dislodging ($p = 0.05$) and low collection and capture efficacies (Figs. 6 and 7). On the other hand, the proportion of dislodged larvae found in the alley increased with travel speed (Fig. 7). All these effects were linear. Blocks significantly affected the collection efficacy and the proportion of dislodged insects that dropped in the alley before being collected. Field observations showed that fewer insects dropped in the alley as the day progressed, resulting in an increase in the insect collection efficacy, until about 5:00 pm when the trend was reversed. Additional testing is therefore required to investigate these temporal effects.

Energy requirements of the prototype

The power required by the blowing unit exponentially increased with increasing airflow velocity as illustrated in Fig. 8. On the other hand, narrower airflow width resulted in a reduction in the power requirements for a given airstream velocity. That reduction ranged from 1 to 2.7 kW depending on airflow velocity. The power required is highly correlated with airflow velocity and width ($R^2 > 0.99$).

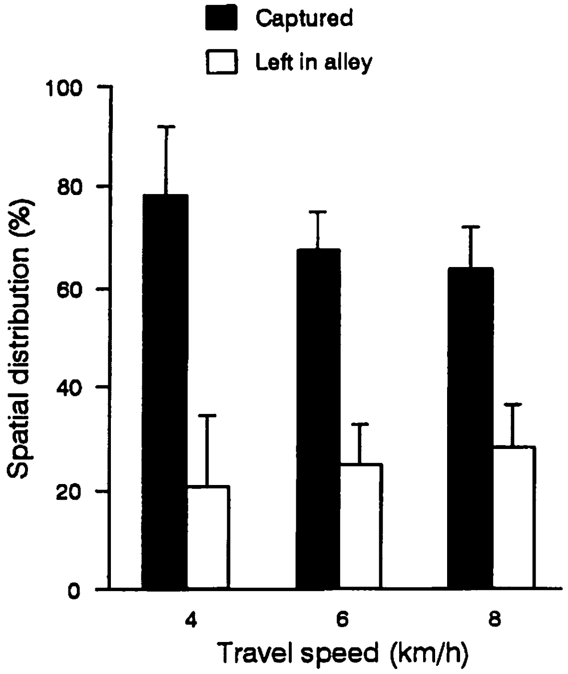

Fig. 7. Effect of travel speed on the spatial distribution of CPB L4 larvae (standard deviation is shown with the means).

CONCLUSIONS and RECOMMENDATIONS

Airflow velocity, in the 30 to 50 m/s range, did not have a significant effect on the dislodging efficacy of CPB adults. However, the effects of airflow width have to be further investigated. The dislodging efficacy averaged only 61% whereas 88% of the dislodged adults were collected. Future work on CPB adults should therefore concentrate on dislodging.

Also, airflow velocity didn't significantly affect the collection efficacy of CPB adults and L1, L2, and L4 larvae. Therefore, an eventual efficient mechanical system for dislodging these insects could result in the use of reduced airflow velocity. This would allow for the design of wider pneumatic systems that could cover more rows and yet require the same power. With such pneumatic systems, it would be possible to investigate the effects of the pneumatic control process on potato plant growth and crop yields according to different management strategies like treatment dates and frequencies.

Although low travel speed yielded higher insect capture efficacy for L3 and L4 CPB larvae, it seems possible to operate at speeds of about 6 km/h while maintaining a good capture efficacy. This could allow for an increase in the field capacity of the pneumatic system (ha/h). If further studies show that only a low proportion of L1 and L2 larvae can regain the potato plants after being dislodged, pneumatic control will also prove to be interesting for these small larvae.

The power required by the pneumatic system exponentially increased with increasing airflow velocity. Narrower airflow width resulted in a substantial reduction in the power. The use of a mechanical shaking system to dislodge the CPB from the foliage is therefore crucial for saving energy.

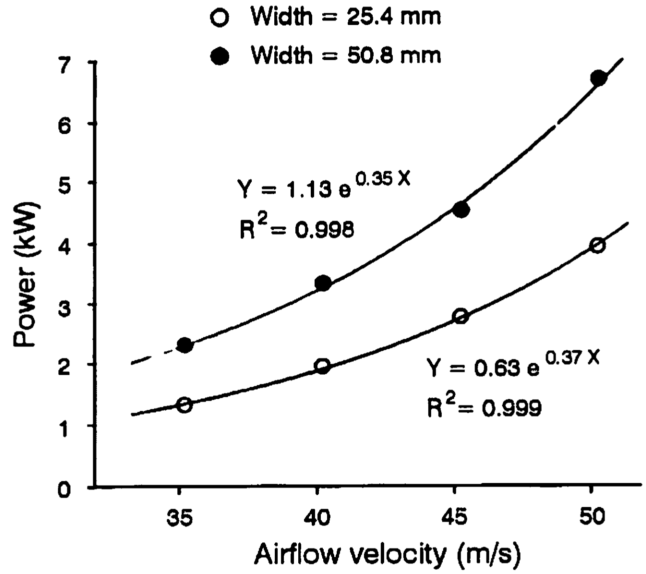

Fig. 8. Effects of airflow velocity and width on the power requirements of the blowing unit.

This study demonstrated the potential of the pneumatic control of CPB adults and L3-L4 larvae. The pneumatic system could be operated at a reasonable travel speed (6 km/h) while maintaining a good collection efficacy. However, further investigation into the behavior of the CPB, in particular the thanatosis phenomenon exhibited by adults and the spatial distribution according to the weather conditions and the population density is required to determine the optimum operating conditions.

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