Effects of airflow velocity and travel speed on the removal of Colorado potato beetles from potato plants

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Lacasse, B. Laguê, C., Khelifi, M. and Roy, P.-M. 1998. Effects of airflow velocity and travel speed on the removal of Colorado potato beetles from potato plants. Can. Agric. Eng. 40:265-272. The effects of different combinations of airflow velocity and travel speed on the dislodging and collection of adults and fourth instar larvae (L4) of Colorado Potato Beetle (CPB), Leptinotarsa decemlineata (Say), were investigated. Two series of experiments were conducted for this purpose, one in the laboratory and the other in the field. In the laboratory, CPB adults were exposed to horizontal airstreams of different velocities ranging from 20 to 35 m/s at three different levels of travel speed (4, 6, and 8 km/h). In the field, L4 larvae were also exposed to horizontal airstreams of 20, 30, and 40 m/s at three travel speeds (2, 4, and 6 km/h). Results revealed that both airflow velocity and travel speed significantly increased the dislodging of CPB adults and L4 larvae. The collection of CPB adults and L4 larvae also significantly increased with increasing airflow velocity. However, the travel speed did not have any significant effect on the collection of adults and L4 larvae. A passive collecting device was adequate. Compared with a vacuuming collecting system, this passive device could greatly reduce the power requirements. The overall results obtained with the prototype were satisfactory. However, more work is needed to improve the dislodging of CPB. This could be achieved by integrating a mechanical shaking system to the prototype machine. Keywords: Colorado potato beetle, insect control, pneumatic, air flows, potato.

Les effets de plusieurs combinaisons de flux d’air et de vitesses d’avancement sur le décrochage et la collecte des adultes et des larves de quatrième stade du doryphore de la pomme de terre (DPT), Leptinotarsa decemlineata (Say), ont été déterminés. Deux séries d’expérience ont été effectuées à cet effet: une série en laboratoire et l’autre au champ. En laboratoire, des doryphores adultes ont été exposés à des flux d’air horizontaux ayant des vitesses d’écoulement comprises entre 20 et 35 m/s et ce, pour trois vitesses d’avancement (4, 6 et 8 km/h). Au champ, les larves de quatrième stade ont aussi été exposées à des flux d’air horizontaux de 20, 30 et 40 m/s et ce, pour trois vitesses d’avancement (2, 4 et 6 km/h). Les résultats ont montré que la vitesse de l’air et la vitesse d’avancement ont significativement augmenté le décrochage des adultes et des larves de quatrième stade du DPT. La collecte des adultes et des larves de quatrième stade du DPT a aussi significativement augmenté avec l’augmentation de la vitesse de l’air. La vitesse d’avancement n’a par ailleurs eu aucun effet significatif sur la collecte des adultes et des larves de quatrième stade. L’unité passive de collecte était adéquate. Comparée à un système de collecte par aspiration, cette unité passive pourrait réduire davantage la puissance requise. Les résultats globaux obtenus avec ce prototype ont été satisfaisants. Toutefois, plus de travail est requis pour améliorer le décrochage des DPT. Ceci pourrait être accompli en intégrant un système d’agitation mécanique à la machine. Mots clés: Doryphore de la pomme de terre, contrôle des insectes, pneumatique, écouléments d’air, pomme de terre.

INTRODUCTION

The Colorado Potato Beetle (CPB), Leptinotarsa decemlineata (Say), is the most important defoliating insect pest of potato plants, Solanum tuberosum L. (Ferro 1985). In the early days of potato production, CPB control was achieved by simply shaking the larvae off the plants and collecting the more mobile adults. Today, over one century after the introduction of the first insecticide against this insect pest (Hurst 1975), many CPB populations are showing some resistance to most types of insecticides (Furgach 1985).

The monetary and environmental costs associated with the use of higher dosages of insecticides and the increasing difficulties and costs of developing new efficient insecticides (Metcalfe 1980) have significantly increased the need to develop alternate methods for controlling the CPB. Crop rotation, for example, can delay field colonization by CPB adults, thus eliminating one or more insecticide applications (Hare 1990). However, the control of CPB over the remainder of the season is imperative. For this purpose, a number of methods, such as flaming (Duchesne et al. 1992), biopesticides, and the development of potato varieties genetically resistant to CPB (Hare 1990) have been investigated. However, none of them can result in an efficient control of the CPB at all life stages (larvae and adults).

The use of airstreams to dislodge and collect insects from plants was tried before DDT came along. This concept has regained popularity in recent years as adequate control of small flying insects by pneumatic systems, especially in strawberry and lettuce fields located in California, has been reported (Boiteau et al. 1992). On the other hand, the use of pneumatic systems to control CPB in potato fields has only been partially successful. This is mostly attributed to the inadequate design of the operating units as no relevant scientific data are available in the literature (Khelifi et al. 1996). Therefore, the effects of different airflow velocities and machine travel speeds on the dislodging of adults and fourth instar CPB larvae were investigated. Two experimental collecting devices for the capture of the dislodged insects were also tested.

BACKGROUND

The pneumatic control of insects is a two-step process. The airstream directed towards the crop must first dislodge the insects from the foliage and then carry them out of the plant canopy to a collecting device.
Dislodging
It is common behavior for many CPB adults to readily drop to the ground when they are disturbed (i.e. when under attack by a predator or when the plants on which they feed are shaken). In other situations however, they can strongly hold on to plant leaves. This allows them to successfully resist airstreams of high velocities (deVries 1987). At this stage, no precise information was found on either the factors that may stimulate both behaviors or the proportions of insects that would behave alike depending on the situations. The most plausible hypothesis at this level is that the pneumatic dislodging of CPB adults will likely be lower on windy days since the insects should be induced to better maintain their grasp on the plant leaves.

CPB adults can grab at objects by two different means. They can use tarsal hooks located at the end of each leg. In addition, scoop-like hairs, located on only male’s tarsal pads, make them better adhere to smooth surfaces such as plastic and glass (Pelletier and Smilowitz 1987). This morphological difference helps also in securing the male on the female during mating.

However, the effect of these hairs does not seem to significantly improve the holding capacity of CPB on potato leaves. Misener and Boiteau (1991) measured the forces required to remove CPB adults placed at different locations on potato leaves. Their results showed that CPB females were slightly more resistant to pulling from the lower surface or the edge of the leaves than males. deVries (1987) found similar values of pulling forces for CPB located on the upper surface of potato leaves and higher values for CPB grasping the underside of the leaves. Better pneumatic dislodging of CPB can therefore be achieved when most of the insects are on the top of the potato leaves.

Misener and Boiteau (1991) also showed that the removal force of CPB L3 and L4 larvae was independent of their position on the leaves. Their holding capability was, however, better when they used their mandibles than their tarsi. According to Misener and Boiteau (1991), the larval legs are less suitable for fast movements which often prevent them from rapidly reaching leaf veins where they could better hold on to the leaves.

deVries (1987) exposed CPB adults to increasing air speeds and also carried out an informal field test to compare airstreams of reduced velocity and light shaking of the plant. deVries (1987) concluded that high air speeds are more needed to transport the beetles rather than to dislodge them. Khelifi et al. (1995a) exposed CPB adults to different combinations of airstreams and found that dislodging of the insects was higher for horizontal airflows across the plants. The experiments of Khelifi et al. (1995a) also showed that ascending airstreams tended to pull up the leaves together towards the central axis of the plants, thus shielding many insects from the airflow effects.

In the field, potato plants will be exposed to airstreams for very short periods of time. Unfortunately, no information about CPB dislodging by airstreams during such periods was found in the literature.

Capture
Dislodged CPB must be carried away from the plants to a collecting device by the airstream. Therefore, the terminal velocity of the CPB has to be known to determine the minimal airflow velocity required for its transport. Misener and Boiteau (1992) reported that the terminal velocities of the CPB adult and the fourth, third, and second instar larvae were $9.43 \pm 0.88$, $9.49 \pm 0.63$, $7.31 \pm 0.55$, and $5.87 \pm 0.15$ m/s, respectively.

Collection efficacy
Some methods were used by researchers to evaluate the collection efficacy of insects. Boiteau et al. (1992) used a method similar to pest insect monitoring. They randomly selected some plants in each plot and counted the insects on these plants before and after conducting the pneumatic treatments. Boiteau et al. (1992) also used another method relying on the use of microplots that were monitored for CPB immediately before and after the pneumatic treatments. Insects fallen on the ground could then be accounted for with this evaluation technique. For both methods, initial and final CPB population densities were compared to determine whether or not the treatments had a significant effect. This also gave a good idea about the global collection efficacy.

Plant resistance to airflow
To prevent damaging the potato plants with pneumatic control systems, it is imperative to know the maximum airflow velocities that can be safely applied. For this purpose, deVries (1987) used greenhouse-grown potato plants (cv. Rosa). He consecutively exposed the plants to three airstreams of different velocities for 30 s. In general, two types of damage were observed, some leaves lost small pieces and others were axially torn. According to deVries (1987), the damage increased with the exposure time because of the tears and twists caused by the flapping of the leaves.

Similarly, Khelifi et al. (1995b) investigated the resistance of potato plants (cv. Kennebec, Norland, and Superior) to airflow. Three stages of growth were considered. The plants were exposed to airstreams for 20 s. Seven levels of airspeed in the 12.5-31 m/s range were used. Results revealed that important damage was induced to the plants at an airflow velocity of 31 m/s. Although potato plants of the variety Superior demonstrated a slightly better resistance to airstreams having velocities of 27 and 31.5 m/s, plant variety was not found to be a significant factor. The resistance of the plants was highly related to the air speed and their stage of growth. Stem flexion increased with airflow velocity and plant height.

While testing a prototype in the field, deVries (1987) noticed that potato plants could support airflow velocities as high as 56 m/s at the nozzle outlet without being seriously damaged. deVries (1987) also investigated some factors that could affect the strength of the potato plant leaf tissue. He reported that leaves under water stress were stronger than those fully turgescant. On average, leaflets of the variety Superior were more resistant than those of the variety Hudson.

It can be concluded that the resistance of potato plants to airflow is inversely proportional to their period of exposure. The resistance to airflow may also vary according to the cultivar, the water potential of the plants, and their stage of growth.
Fig. 1. Test bench used to study the effects of airflow velocity and travel speed on dislodging and collection of CPB: (1) mobile carriage, (2) blowing unit, (3) vacuuming unit.

OBJECTIVES

The objective of this study was to evaluate the effects of airflow velocities and travel speeds of a pneumatic system on the dislodging and collection of CPB. In addition, a passive collecting device for the dislodged insects was designed and evaluated.

MATERIALS AND METHODS

Laboratory experiments

These experiments were conducted in July, 1993, on CPB adults at the Department of Soil Science and Agri-Food Engineering of Université Laval, QC. The dislodging of CPB was evaluated over different combinations of airflow velocities (20, 25, 30, and 35 m/s) and travel speeds (4, 6, and 8 km/h). The collection of the dislodged insects was achieved with a vacuuming system.

A test bench that could accommodate up to three potato plants at a time and move them at the desired travel speed across a uniform air curtain of known velocity was used (Fig. 1). The test bench consisted of an eight meter long table supporting a mobile carriage on which the potato plants were placed. The carriage track was padded with foam to reduce vibrations during travel. The carriage was pulled by an elastic cable engaged around two pulleys placed at both ends of the table. One pulley was driven by a variable speed electric motor allowing for adjustable acceleration and deceleration phases of the carriage. For practical considerations, plants were displaced rather than the airflow. The smooth acceleration of the plants was assumed to have no effect on the CPB adults.

A blowing unit (Figs. 1 and 2) was installed on one side of the table near the end of the stroke of the mobile carriage. It consisted of a wooden box connected to a centrifugal fan. Air was blown out from a vertical slot located at the front of the box. During their travel, potato plants crossed the airstream and then slowed down after the carriage had actuated a limit switch.

On the other side of the table (i.e., opposite side), another centrifugal fan was installed in front of the blowing unit to vacuum the dislodged insects. Airflow velocity at the inlet of the vacuuming unit was adjusted according to the velocity at the outlet of the blowing unit. A plastic grid, placed over a screen mesh covering the vacuum inlet, prevented the dislodged CPB from being sucked into the fan. A horizontal grating of iron bars spaced at intervals of 25 mm was mounted in front of the vacuum unit inlet (Fig. 2) to hold the potato plants in a vertical position when crossing the airstream.

Motor shaft speed was controlled to provide the selected carriage travel speed. Motor shaft speed was measured with an optical tachometer (Model 3404, Hioki Corporation, Nagano, Japan). Airflow velocities were measured with a 2% precision telescopic anemometer (Solomat Instrumentation Division, Norwalk, CT) at the plant level, 150 mm away from the outlet of the blowing unit. Velocity variations within the air curtain averaged 5%.

The blowing unit outlet and vacuuming unit inlet were 75 mm wide by 220 mm high and 180 mm wide by 330 mm high, respectively. The axes of the two units were aligned on the same vertical plane and the bases of the two units were placed at the same height. The blowing unit outlet was 150 mm away from the center of the carriage path. The steel grating was 105 mm away from the center of the carriage path and the inlet of the vacuuming unit was 100 mm behind the grating. Potato plants were about 300 mm tall and could be fully exposed to airflow with this apparatus.

Potato tubers (cv. Superior) were seeded on May 14, 1993, in 150 mm diameter pots and grown in a greenhouse. Only one stem was kept on each plant. CPB adults were collected from a field located at Ile d’Océans (Québec) about one week after

Fig. 2. Enlarged view of the blowing unit outlet (left) and the vacuum unit inlet (right).
Fig. 3. Overall view of the field prototype.

their emergence to the ground surface. Average temperature during the tests was 26.2 ± 1.5°C.

Fifteen CPB adults were released on the plants three hours before testing in order to settle themselves on the foliage. Immediately before and after the passage of the carriage through the airstream, total insect counts on the three potato plants were made. Each combination of airflow velocity and travel speed was replicated three times.

For this experiment, an analysis of variance was performed to determine the effects of airflow velocity and travel speed on the dislodging and collection of CPB. Data analysis was carried out at the 5% level using the General Linear Models (GLM) procedure (SAS 1988). A logarithmic transformation (log Y) was performed on the dislodging data to improve the homogeneity of variances (Steel and Torrie 1980). Variables with significant F values were further analyzed using Duncan’s Multiple Range test at the 5% level of significance.

Field experiments

A blowing unit similar to that used in the laboratory was mounted in front of a farm tractor. On the other side of the potato plant row, a screen mesh collecting device was installed facing the blowing unit (Figs. 3 and 4). This collecting device replaced the vacuuming unit used in laboratory tests. A PTO-operated centrifugal fan delivered air to the blowing unit through rigid and flexible pipes (Fig. 3). The angular speed of the fan was adjusted by varying the PTO speed. There was a clearance of 304 mm between the blowing unit outlet and the grating of the collecting device. The blowing unit opening was only 50 mm wide to obtain higher airflow velocities than in the laboratory. During the field trials, potato plants were 430 mm tall and 580 mm wide on average.

This field study was conducted in August, 1993, 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 15 by 131 m, were seeded with potato tubers (cv. Kennebec) on June 25. The tubers were seeded at 250 mm intervals along rows spaced 910 mm apart. The plots were chemically treated for weeds and mildew control using mainly Metrobromuron and Metalazol-Manzozebe, respectively.

Row sections of seven plants each were used as experimental units. These sections were selected at the beginning of the testing session (in the morning). The selection criteria were sufficient populations of CPB, similar plant dimensions, and low plant defoliation. The order of the treatments and the assignment of the experimental units were then randomized within these sections.

To ensure that all counted beetles came exclusively from the experimental units, potato plants located two meters before and one meter after the selected row sections were removed while the plants located on each side of these sections were laid down. CPB larvae present on the potato plants before and after the treatments were counted along with those captured in the collecting device. Two persons counted the larvae on the plants, before and after the pneumatic treatment, and two others counted the collected ones.

The calibration of the airflow velocity was made with the same telemetric anemometer used in the laboratory experiment. Airflow velocity was measured at the plant level, 150 mm away from the outlet of the blowing unit.

The original experimental design was aimed at testing full combinations of three travel speeds (2, 4, and 6 km/h) and three airflow velocities (20, 30, and 40 m/s) on L1-L4 CPB larvae. However, rainy conditions and mechanical problems limited the experiments to only L4 larvae. Each combination of travel

Fig. 4. Blowing unit (1); collecting device (2) of the field prototype.
speed and airflow velocity was replicated four times. An analysis of variance using the General Linear Model procedure (SAS 1988) was performed on the obtained data at the 5% level of significance. Significant means were further separated using Duncan’s Multiple Range test at the 5% level of significance.

Visual sorting and counting of large amounts of CPB in a short period of time is prone to some errors that could be misleading. For example, the number of larvae counted in some experimental units after finishing the treatments exceeded the initial number. This presents the risk of overestimating the dislodging and collection efficacies by underestimating the initial population. To partially remedy this problem, some of the initial populations were corrected to equal the number of beetles found after the treatments.

RESULTS and DISCUSSION

Laboratory experiments

Dislodging of CPB adults The analysis of variance revealed that the effect of airflow velocity on the dislodging of CPB adults was highly significant ($p = 0.0001$). The travel speed also significantly affected the dislodging of CPB adults ($p = 0.034$). However, the interaction between airflow velocity and travel speed was not significant ($p = 0.45$). Higher airflow velocities resulted in an increase of insect dislodging whatever the travel speed used (Fig. 5). The use of an airflow velocity of 35 m/s had a comparable dislodging efficacy to that of 30 m/s (Fig. 6). The use of airflows of 20 and 25 m/s speeds resulted in lower efficacies. Higher travel speeds (i.e. shorter periods of exposure), in particular 6 km/h, also increased the dislodging of CPB (Fig. 7). This latter result is of great importance as it allows for greater field capacity (ha/h) of the pneumatic system. The dislodging of CPB was complete (100%) for travel speeds of 6 km/h or more and an airflow velocity of 35 m/s (Fig. 5).

The increase of dislodging with increasing travel speed could be explained by the enhancement of plant shaking as they slide rapidly against the grating. Also, the exposure of CPB to airflow occurs over a shorter period of time at higher travel speeds. This gave them less time to strengthen their grip on the plants. At this stage, it was not possible to distinguish between the respective effects of airflow velocity and mechanical shaking since the friction force of the plants on the grating is proportional to the airflow velocity.

For this experiment, an airflow velocity of 35 m/s was not sufficient to dislodge all the CPB adults at a travel speed of 4 km/h. Higher travel speeds were then required to obtain complete dislodging. The effect of mechanical shaking of the plants is therefore important in dislodging the CPB. It has to be mentioned that the dislodging efficacies measured in this
experiment could probably be overestimated since potato plants had only one stem.

**Collection of CPB adults** The airflow velocity significantly increased the collection efficacy ($p = 0.0001$). However, the travel speed was not significant ($p = 0.08$). The interaction between airflow velocity and travel speed also was found not to be significant ($p = 0.23$). The use of an airflow of 35 m/s yielded the best collection efficacy compared with 20 m/s (Fig. 8).

Turbulent airflow across the rows of potato plants caused a major problem in collecting the CPB as many of these insects were blown away in different directions. Consequently, about half of the dislodged CPB were not collected. Some of them may have not been blown with sufficient speed to reach the collecting device while others may have been deflected by the leaves or the stems and bounced beside the vacuum unit inlet. To reduce the turbulence effect, some screens allowing the air to settle before passing could be used as mentioned by deVries (1987).

During these preliminary tests, the effects of turbulence on the collection of CPB were obvious, especially at high airflow velocities. Unfortunately, it would be very difficult to build a blowing-vacuuming system in closed circuit because of the practical constraints on one hand and the energy requirements of the vacuuming unit on the other.

**Field experiments**

**Dislodging of CPB larvae** Figure 9 shows the dislodging efficacy of CPB L4 larvae under the effects of different airflow velocities and travel speeds. The analysis of the results revealed that the effects of airflow velocity and travel speed on dislodging of L4 larvae were highly significant ($p = 0.0001$ and 0.0047, respectively). However, the interaction between airflow velocity and travel speed was not significant. Consequently, only the main factors, namely airflow velocity and travel speed, independently affected the dislodging of L4 larvae from potato plants. In contrast to 2 km/h, the use of 4 and 6 km/h travel speeds yielded comparable dislodging efficacies (Fig. 10). In general, field operation at high airflow velocity (40 m/s) resulted in the highest dislodging efficacy whatever the travel speed used. The effect of airflow velocity on dislodging was important as shown on Fig. 11. Compared with 40 m/s, the use of airflows of 20 and 30 m/s speeds resulted in lower dislodging efficacies.
Collection of CPB larvae  The analysis of the results showed that the effect of airflow velocity on the collection of L4 larvae was highly significant (p = 0.0001). However, neither the travel speed nor the interaction between airflow velocity and travel speed were found to be significant. An airflow velocity of 40 m/s resulted in the highest collection efficacy of L4 larvae (Fig. 12). Based on the number of dislodged insects, this configuration (transversal blowing, passive collecting device) yielded an interesting capture rate of L4 larvae at 40 m/s (≈ 87%). This means that the collecting device used for this prototype is more adequate than the other vacuuming systems reported in the literature and may not need any major improvements.

In general, visual observation made in the field showed that damages to potato plants remained low and tractor wheels were mostly to blame rather than the pneumatic control unit itself. At 40 m/s, only a few small pieces of leaflets were found in the catching unit after treating a 15 m long row.

CONCLUSIONS and RECOMMENDATIONS

1. The effects of airflow velocity and travel speed on dislodging of CPB adults and L4 larvae were highly significant. Higher airflow velocities and higher travel speeds (i.e. shorter periods of exposure) resulted in increased insect dislodging. This suggests that it is possible to cover large areas of potato fields in a reasonable time with a pneumatic system.

2. The effect of airflow velocity on the collection of CPB adults and L4 larvae was also highly significant as higher airflow velocities yielded an increase in the collection of dislodged insects. However, the travel speed did not significantly affect the collection of CPB adults and L4 larvae.

3. The passive collecting device used during the field experiments was adequate and may not need any major improvements. Compared with a vacuuming collecting device, the use of such a passive collecting unit could greatly reduce the power requirements. The energy thus saved could be used to improve the blowing system.

4. Field observations made during the experiments showed that the damage caused to potato plants by the pneumatic system was low as only a few small pieces of leaflets were found in the collecting unit after each treatment. For short periods of exposure, potato plants could sustain airstreams of a velocity as high as 40 m/s. The damage caused by the tractor wheels was however more serious.

5. Although a satisfactory collecting efficacy was obtained with this basic prototype using a horizontal airflow across the plants and a passive (non vacuuming) collecting device, more work is needed to further improve the dislodging of CPB. This could be achieved by adding a mechanical shaking system to the prototype machine.

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