Mechanical Distribution of Natural Enemies in the Open Field

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Abstract

For experimental trials in strawberry open field, two different applications of a new version of a prototype, built for mechanical distribution of natural enemies, were used: one mounted on a bar carried by an operator with a shoulder strap and lateral handle; the other mounted on a carrying bar connected to three linkage points to a tractor. In this case, three prototypes were attached to three support rods and connected electrically to one another in parallel, powered by a single battery and commanded by a single switch, positioned near the tractor driver.
In this configuration, laboratory trials to evaluate the throw direction, the spatial distribution, the quantity distributed, the uniformity of throw in time were carried out.
Previous laboratory trials were carried out to assess the performance of the new version of the prototype and to set the suitable flow rate for the distribution in open field with reference to the forward velocity of the tractor.
With these applications of the new version of prototype, the manoeuvrability has been much improved and consequently better results can be obtained in terms of both work capacity and uniformity of distribution. The high values of the Uniformity Index and Similarity Index confirm that the application of the prototype mounted on the carrying bar could represent a suitable solution for the distribution of natural enemies in strawberry crops. Also the work capacities show the advantage using the machine tested as opposed to the manual distribution generally adopted for biological and integrated crops.

Keywords: machines for biological plant protection, sustainable agriculture, safety, prototype

Introduction

The manual release of natural enemies onto infested plants takes up a considerable amount of the operator's time and, moreover, does not ensure uniform distribution. In order to contain the production costs connected with defence operations and to favour a wider use of biological products, various solutions have been examined (Baraldi *et al.*, 2006; Drukker *et al.*, 1993; Giles *et al.*, 1995; Giles & Wunderlich, 1998; Gill *et al.*, 1999; Maini *et al.*, 1988; Opit *et al.*, 2005; Pezzi *et al.*, 2002; Pickett *et al.*, 1987; Van Driesche *et al.*, 2002). The Department of Agricultural Engineering at the University of Catania has realised a prototype to mechanise the release of natural enemies, which are commonly used for biological control on vegetable crops in protected environments and in the open field. The results obtained were such as to lead to the conclusion that the prototype is suitable for use in biological control programmes (Blandini et al., 2008; Tropea Garzia *et al.*, 2006).
Since then, a second version of the prototype has already been built This differs from the preceding one not only as regards the hopper, doser and distributor disc but also as regards materials and size. It can directly carried by the worker by means of an handle.

The Authors equally contributed to the present study.

To evaluate the functionality of the new prototype several laboratory trials were carried out and three prototypes were built and installed on a bar tractor mounted for treatments in the open field in order to demonstrate their versatility in various agronomic and environmental conditions. Finally open field trials on two different strawberry fields (with and without cover tunnel in plastic film) were carried out.

Materials and Methods

The most recent version of the prototype and his applications

The prototype used during the experimental trials is a new version of the initial one described in Blandini *et al.* (2006). The modifications regard some of its components (Figure 1):

- the hopper is smaller (about 1.5 dm^3) than the previous version and is made of aluminium to permit better centring of the doser with respect to the exit hole for the product;
- the doser, rotating inside the hopper, is obtained from the tip of a drill for concrete, with the cutting elements at the end removed; it has two holes in the stem for the attachment of two fins;
- the fins are made of a flexible plastic material, which are positioned at different heights and ensure that the product flow towards the exit hole;
- the finned distributor disc has a diameter of 300 mm instead of the 200 mm of the previous version and it is made of aluminium;
- the connection between the bar, held by an operator, and the prototype is realised by means of a cylindrical hinge made up of two circular plates, bolted together, one applied to the end of the bar and the other in the posterior area of the prototype frame (Figure 2);
- the two plates have small frontal teeth along a circular crown, in order to permit almost continuous regulation of the angle of tilt of the bar's axis with the plane of the distributor disc and guarantee its constancy while the prototype is working.

Figure 1. The most recent version of the prototype used for the test.

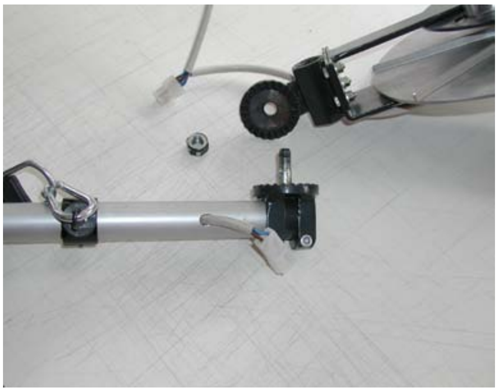

Figure 2. The cylindrical hinge.

The hopper contains the arthropods to be distributed together with the substrate (humid vermiculite at 30% for the *Phytosiulus persimilis* Hathias Herriot and buckwheat husks mixed with vermiculites for the *Orius levigatus* (Fieber)) with which they are marketed.

The doser and the distributor disc are directly activated by two electric motors powered by continuous 6 V current, positioned below the disc and fixed to the lid of the hopper respectively.

The doser has a rotating motion coinciding with the axis of the hopper and, therefore, of the exit hole for the product. Regulation of the amount of the product to be distributed takes place

by varying the diameter of the exit hole of the hopper by means of bushings of different diameters with external thread, which can be screwed to the hopper. Moreover the tightening of the bushings makes possible to fix the hopper to the supporting disc, which has a radial loop. Regulating the position of the hopper along the loop and rotating the support disc around the point of anchorage to the frame, it is possible to vary the launch direction of the natural enemies onto the crops from the distributor disc.
Two different applications of this version were used for experimental test in open field:

- one mounted on a bar carried by an operator with a shoulder strap and lateral handle;
- the other mounted on a carrying bar connected to three point linkage to a tractor.

For this second application, three prototype was applied on three support rods with an hexagonal cross-section arranged vertically. The prototypes were connected electrically to one another in parallel, powered by a single 12 Ah rachargeable battery and commanded by a single switch, positioned near the tractor driver.
The height of the prototypes can be regulated and the best distance separating them can be chosen according to the arrangement of the crop in the field (equidistant and twin rows, etc.).

Laboratory trials to assess prototype performance
It is known by literature that in greenhouse it is necessary to distribute 10-15 examples of *P. persimilis*/m^2) and 1-3 examples of *O. laevigatus*/m^2. Taking into account the mass of the substrate and the amount of arthropods in a package and hypothesising a forward speed of 3 km/h and an effective distribution range of 1 m, the optimum capacity of flow is about 9 g/min for the *P. persimilis* and about 6 g/min for *O. laevigatus*.
To obtain this flow, several trials were carried out positioning the hopper and its doser over a precision balance so that it was possible to constantly weigh the quantity of product released by the machine. It was measured for dosers with different diameters (14 and 15 mm) and for different hopper exit hole diameters (14, 15, 16 and 17 mm). The uniformity of release in time was assessed by measuring - at 30-second intervals - the quantity of antagonists dispersal material. Each trial was repeated 3 times filling the hopper with the mass of one (*O. laevigatus*) or two (*P. persimilis*) packages every time.
Particular attention was paid to the length and orientation of the flexible fins in the doser, so as to guarantee continuity as regards product flow.
The assessments of the material launch distance were carried out (with the collaboration of entomologists) positioning the prototype at a height of 40 cm from a horizontal purpose-built plane. This 180×140 cm plane was divided into 15 sectors (5×3 rows). For the collection of the *P. persimilis* 36×47 cm plastic trays containing a thin veil of water were used. Instead, for *O. laevigatus* the point at which each individual fell was marked on a sheet of paper.
Other tests were carried out with the prototypes carried by the tractor and using only the dispersal material of the natural enemies. For each of the two substrates and for each prototype:

1. the position of the hopper was regulated to optimise the direction of the jet;
2. the quantity and uniformity of the product distribution in time was assessed;
3. the transversal profile of this was checked.

The quantity of product simultaneously distributed (g/s) by the 3 prototypes was studied by weighing the material released by each prototype inside purpose built boxes. The trials were repeated at 2-minute intervals.
The transversal profile of product distributed was measured for the two substrates at two different prototype heights (50 and 100 cm from the ground). The material was collected in 32 of 33×39 cm aluminium trays (8×4 rows) for a covered horizontal surface of 156 cm long and

264 cm wide. The trials were repeated 3 times for each trial condition and for each substrate.
In order to express an assessment of the transversal uniformity for each trial condition, the Uniformity Index (UI) calculated with the following equation (Cerruto *et al.*, 2009) was used:

$$IU = 1 - \frac{\sum_{i=1}^{n} \left| \frac{y_i}{y_m} - 1 \right|}{2n} \qquad (1)$$

where:
- y_i is the quantity of product collected in every row;
- n is equal to the number of rows;
- y_m is the arithmetic mean of the quantity of product collected in all the rows.

This index, which will have a value between 0 and 1, is a measurement of how far the real profile obtained differs from the ideal one, which is constant and equal to its corresponding average value.
The difference between two profiles, y_1 e y_2, was measured by calculating the Similarity Index (SI), defined by the equation (Cerruto *et al.*, 2009):

$$IS = 1 - \frac{\sum_{i=1}^{n} \left| y_{1i} - y_{2i} \right|}{\sum_{i=1}^{n} \left| y_{1i} + y_{2i} \right|} \qquad (2)$$

which again gives values between 0 and 1: the nearer the result is to 1, the more similar the profiles are. This formula refers to profiles obtained in the same conditions and so to compare values obtained in different conditions (in terms of material distributed and/or prototype height), the data were first normalised in such a way that $\sum_{i=1}^{n} y_{1i} = \sum_{i=1}^{n} y_{2i} = 1$

The open field trials
Open field trials on two different strawberry fields (without and with cover tunnel in plastic film) were carried out. Both fields were located in the commune of Cassibile (SR) on sloping flat land. The cultivation takes place on 0.8 m large ridges covered with black plastic film to give a mulch effect. The distance between two ridges was around 0.6 m.
The first trials were on Camarosa cultivar strawberry fields without cover tunnel. On every ridge there were two rows of plants 0.3 m apart; the inter-row distance of two plants was 0.25 m, so the plant density was 8 plants/m^2. Instead, the other trials were on Carmela cultivar strawberry fields with cover tunnel. In this case the inter-row distance was 0.2 m and consequently the plant density was 12 plants/m^2.
For the distribution trials in the first field three prototypes mounted on a 3.2 m carrying bar and connected to three point linkage to a 2 WD tractor were used (Figure 3). During the trials the prototypes were regulated at an average height of 50 cm from the ground and at an inter-row distance of 1.4 m, so that each one was also positioned in correspondence of the centre line of each ridge. Consequently, the work width was 4.2 m. The area considered for the experiments was about 600 m^2 and included a total of 6 ridges.
Instead, in the second strawberry field, the trials were carried out on a surface of 150 m^2 including 3 ridges and the prototype applied to the bar carried directly by an operator was used (Figure 4). In this case two treatments with both natural enemies a fortnight apart were carried out.

Figure 3. The distribution with three prototype carried by a tractor.

Figure 4. The distribution with a prototype carried by an operator.

Results

The laboratory trials to assess prototype performance

The trials carried out to define the right flow show to use:

- the 14 mm diameter doser for both substrates;
- the 17 and 15 mm bushing diameters for the buckwheat husks mixed with vermiculite (*O. laevigatus*) and vermiculite on its own (*P. persimilis*) respectively.

The results of the trials carried out with the *O. laevigatus* substrate show (Figure 5) that the quantities released every 30 seconds vary between 5.56 and 2.48 g, with an average of 3.12 g, as expected, and a CV of 21%. Only the highest extreme value can be considered to be influenced by the loading and starting phase, while the quantities of product distributed are fairly constant.

The results obtained with *P. persimilis* and its substrate show that the quantities distributed vary between 18.18 and 3.70 g (an average of 7.21 g), with a CV of 67%. There is, in fact, a significant difference between the first 8 samples (where more than half of the product in the hopper is released) and the remaining 15; this is caused by the effect of the mass present. From the 9th sample onwards, on the other hand, the quantities distributed are fairly constant. This is demonstrate by distributing half mass of product: in fact only the first sample was very different from the average because of the effect of the load. The other values were found to be very uniform (Figure 6) and the CV was 13%.

As regards to the launch distance, it was observed that about 85% of the natural enemies distributed on the horizontal plane were within a distance of 90 cm from the prototype while the inert material exceed one metre.

The transversal distribution profiles, shown in figure 7, represents the average quantities of product collected in the 8 rows and 3 repetitions. They are substantially symmetric and have a CV of 30-34%. Only the lower values found at the lateral edges of the distribution zone can be compensated for a programmed superimposition in subsequent runs.

The results of Uniformity Index exceed always 0.86 for both prototype heights. This means that the product can provide homogeneous cover of the surface treated. Also the Similarity Index exceed 0.92 and therefore the profiles can be considered very similar to one another regardless of the height of distribution of the inert material.

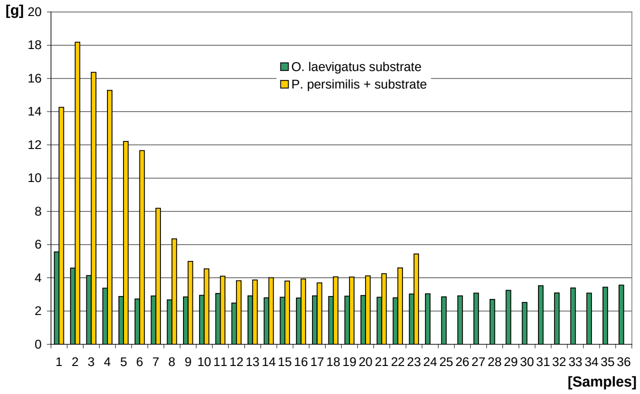

Figure 5. Average values [g] of product released every 30 s.

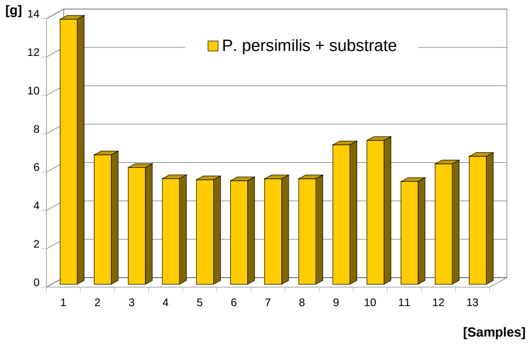

Figure 6. Average values [g] of humid vermiculite released every 30 s with half mass inserted into the hopper.

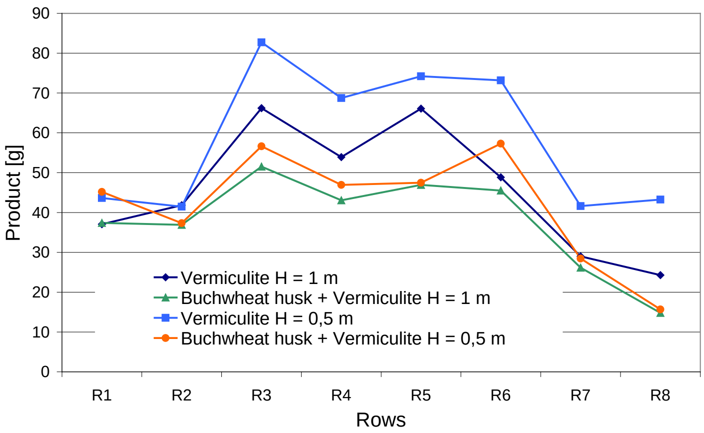

Figure 7. Transversal distribution profiles.

The open field trials

The trials carried out with the three prototypes applied to the 2 WD tractor permitted an effective work capacity of about 0.6 ha/h in the case of *O. laevigatus* and about 1 ha/h in the case of *P. persimilis* to be reached. In fact, the average forward speeds were 1.4 km/h (0.4 m/s) and 2.3 km/h (0.6 m/s) respectively.

For both the natural enemies three packages were used, one for each hopper, distributing about 0.2 g/m^2 in the case of *O. laevigatus* and 0.4 g/m^2 in the case of *P. persimilis*. With respect to the values shown in Table 1, an increase in quantity was observed, particularly for *P. persimilis*, due to spillage from the doser during turning manoeuvres caused by the vibrations transmitted by the tractor. In fact, the headlands were not large enough to allow the fast turning of the tractor equipped with the carrying bar; moreover, the farmer carried out the plant protection treatments with a spray gun carried directly by the operator, so the field was not suitable for mechanised cultivations.

The same increase in quantity was not recorded with the *O. leavigatus* because of greater dimensions of its dispersal material (buckwheat husks mixed with vermiculites) with respect to that used for *P. persimilis*: only vermiculites of small dimensions.

Table 1. Distribution parameters in the first strawberry field where three prototypes in parallel were used.

Prototypes	Distributor disk velocity (rpm)	Doser velocity (rpm)	Flow (g/s)	
			O. laevigatus	*P. persimilis*
1	530	29	0.13	0.55
2	453	27	0.10	0.54
3	448	26	0.19	0.42
mean	*477*	*27*	*0.14*	*0.50*

In the case of the trials carried out in the second strawberry field using only one prototype applied to the bar carried by an operator, the work capacity were significantly lower (about 0.06 ha/h) than those obtained with the tractor carried prototypes. This result was due both to the ability to carry out the treatment on only one ridge at the same time (effective work width of 1.4 m instead of 4.2 m with the tractor) and to the lower forward speed, only 0.43 km/h (0.12 m/s), that was needed to keep the distribution of the packages on the established surface. Finally, it is worth pointing out that on the basis of the information provided by the farmers hosting the trials, it would seem that the productive yield obtained with biological treatments and those with chemical treatments were comparable.

Conclusions

The distribution mechanism of the prototype seems well suited to biological pest control strategies also in the open field. With the two applications of the new version of prototype, the manoeuvrability has been much improved and consequently better results can be obtained in terms of both work capacity and uniformity. The high values regarding Uniformity Index and Similarity Index confirm that the prototype mounted on the carrying bar connected to three point linkage to a tractor could represent an suitable solution for the distribution of natural enemies in strawberry crops. Also the work capacities show the advantage using the machine tested as opposed to the manual distribution generally adopted for biological and integrated crops.

However, it seems useful to consider the use of bigger hopper to reduce the time taken to fill up the hopper when the machine is working, even if this could have negative consequences on the flow’s constancy of the doser. Moreover, to increase the work capacity the headlands would be large enough to allow the fast turning of the tractor and the reduction of the stopping times of the prototypes, so to limit the product lost because of the not inconsiderable vibrations transmitted by the tractor. At last, if there were no problems with turning, it would be possible to increase the work capacity by increasing the work width and consequently the bar length and thus the number of prototypes used.

Economic assessments regarding the relative cost of treatments with natural enemies would supply additional information that could contribute to a global evaluation.

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