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Use of a damage index to evaluate the biological control of the two-spotted spider mite *Tetranychus urticae* Koch (Acari; Tetranychidae) on tomato crops

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SUMMARY

In tomato crops protected by the predatory mite *Phytoseiulus persimilis* against the two-spotted spider mite *Tetranychus urticae* foliage damage showed an oscillatory pattern with increasing amplitude, indicating an unstable prey-predator equilibrium. Cyclical declines in predator populations were met with subsequent rapid increases in prey populations, and as a consequence, considerable numbers of predatory mites were needed to control the spider mites: 25,000 to 36,300 predators per 100 m^2 for a period of 22 to 26 weeks. Only when the spider mites were colonizing was a stable and satisfactory ratio between the number of released predators and foliage damage observed. The instability of the prey-predator equilibrium was attributed to the intensity of the introduction of the predator on each plant and to the unfavourable abiotic environmental conditions.

BIOLOGICAL control of spider mites (Tetranychidae) through the use of predatory mites (*Phytoseiulus persimilis* Athias-Henriot) has been achieved with a number of plant species, e.g., beans, roses and corn (Chant, 1961; Gough, 1991; Pickett and Gilstrapp, 1986). On tomatoes, however, predatory mites have not been widely employed (Van Lenteren and Woets, 1988) despite the fact that techniques for their introduction onto tomato crops have long been established by Hussey and Scopes (1985).

The purpose of our experiment was to establish the nature of prey-predator evolution in tomatoes with the aim of improving biological control of the spider mite. We selected a leaf damage index (Hussey and Scopes, 1985) to monitor the damage caused to leaves by spider mites and to evaluate the populations and aggregation patterns of spider mites on the plants, as it has been shown to give an accurate evaluation of spider mite numbers on leaves (Nihoul *et al.*, 1991). The evolution of the foliage damage was also analysed over a longer period than did Hussey and Scopes (1985). Finally, the numbers of predators necessary to provide effective control of the spider mite were related to the foliage damage.

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MATERIALS AMD METHODS

Field sampling procedure

The experiment was conducted in a 70 m^2 glasshouse (6.4 m wide) in 'Sint-Katelijne-Waver' in Belgium (Dr F. Benoit) over a two year period, during which four tomato crops were cultivated under natural light. Two crops were planted in January and the other two in summer (Table I). Each crop consisted of eight rows of tomatoes planted 55 cm to 60 cm apart. Prior to each planting the soil was cultivated, and 6 kg patentkali, 3 kg N P K (12-12-17) and 2 kg kieserite were incorporated.

A fifth tomato crop, consisting of four rows of tomatoes planted 60 cm apart, was cultivated under natural light in a 40 m^2 glasshouse (3.5 m wide) on rockwool with a nutrient solution mixed according to specification suggested by Musard (1988).

TABLE I
Cultural characteristics of the five tomato crops

Culture	Variety	Date			
		Seedling	Planting	First attacks*	Crop end
1	Vision (Enza) and Contento (De Ruiter)	26-7-89	29-8-89	6-10-89	5-12-89
2	Dombito (Bruisma)	16-11-83	3-1-90	16-1-90	18-7-90
3	Recento (De Ruiter)	26-6-90	25-7-90	24-8-90	13-11-90
4	Capello (De Ruiter)	20-11-90	8-1-91	13-3-91	15-7-91
5	Dombito (Bruisma)	10-1-90	26-2-90	17-5-90	19-11-90

*Attacks of spider mites

The two-spotted spider mite invaded naturally each of the crops. Damage patterns were recorded weekly on the upper ten leaves of each plant using the Mean Leaf Damage Index (MLDI) described by Hussey and Scopes (1985) and Nihoul *et al.* (1991).

The predatory mites *Phytoseiulus persimilis* Athias-Henriot provided by Koppert (the Netherlands) were introduced onto all five crops after infestation by the spider mite. On 17 October, 1989, five predators were introduced onto every two plants in the first crop. On the other four crops, the predatory mites were released only onto leaves already colonized by the prey. The number of released predators was proportional to the number and size of feeding marks: a mean of approximately 1 to 2 *P. persimilis* was introduced onto small patches of the prey (corresponding approximately to a (LLDI) = 2 Leaflet Damage Index (Nihoul *et al.*, 1991), and a mean of about 2–3 predators on larger patches (LLDI$\geqslant$3). But no predators were released onto leaves not colonized by predatory mites. Observation of the foliage was made by means of a 2.5 × hand lens.

Analytical techniques

Number of predators and development of plant damage: A three-dimensional surface graph was produced for the variables, total number of predators introduced (z), the initial plant damage index (y) and the increase in plant damages (x), using G3D Procedure (SAS, 1985). The effectiveness of the MLDI as a predictive tool for managing the quantity of predators to be released was evaluated by the smoothness degree of this surface calculated by a modified version of the Akima's method (1978). The effectiveness of the MLDI as a predictive tool for managing the numbers of predator to be released was evaluated by the smoothness of the calculated surface.

Aggregation of the spider mites: The MLDI was also used to estimate the numbers of spider mites on each plant (Nihoul *et al.*, 1991), and to evaluate the spatial pattern of the spider mite in each of the five crops by measuring the degree of aggregation. The parameter 'b' of the Taylor's Power Law (1984).

$$\mathrm{Ln}(s^2) = a + b\,\mathrm{Ln}(\bar{x})$$

was chosen as it is commonly used (Jones, 1990), and is constant for a given species in a given environment (Taylor, 1984). The distributions of the populations was found to be random when b = 1, and aggregated when b>1 and a$\geqslant$0. A covariance analysis was performed to determine the significant differences of slope (b) between the five crops.

RESULTS

Number of predators and development of plant damage

The most successful control of the spider mite was achieved in the second and fifth cultures, lasting 22 and 26 weeks respectively. A total of 25 000 predatory mites per 100 m^2 were released onto the second culture between 23 January, 1990 and 9 May, 1990. More predatory mites were released onto the fifth culture; on 5 May, 21 June, 5 July and 5 September, 1990 and totalling 36 300 predators per 100 m^2. In neither case was an equilibrium reached between predator and prey. In each case foliage damage oscillated, with increasing amplitude, indicating that the equilibrium between predator and prey was not achieved. Three increasing phases were identified (Figure 1). The third phase was, however, not included in our analyses as it was still in the process of developing when the experiment was terminated:

Crop 2: First increasing phase: The average initial plant damage degree was 0.1 (s = 0.2;

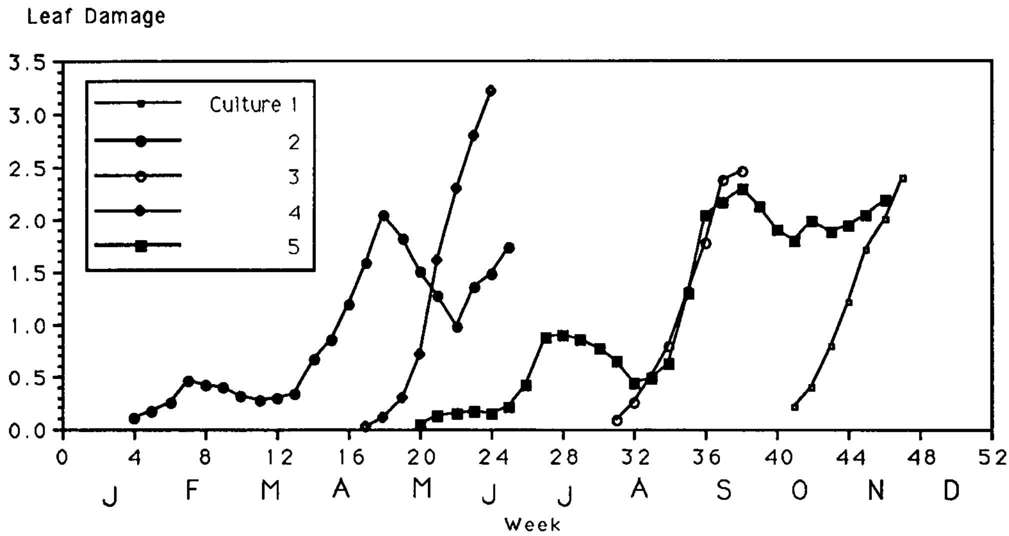

FIG. 1
Development of visual leaf damage caused by *T. urticae* in the five tomato cultures.

plants with 13 leaves) on 23 January, 1990, and reached 0.5 (s = 0.4) after four weeks (s = 1). During this period, 4 300 predators per 100 m^2 were released. Figure 2 shows the number of predators released relative to the initial and subsequent degree of plant damage.

Second increasing phase: The population of spider mites remaining after the first damage increase appeared large. On 27 March, 1991, the degree of damage was 0.4 (s = 0.5), and the mean maximum obtained during five weeks (s = 1) was 1.8 (s = 0.5). Another 16 500 predators per 100 m^2 were released during this period. In this case, the graph representing the number of released predatory mites according to the initial and final levels of damage shows a very irregular surface due to various levels of

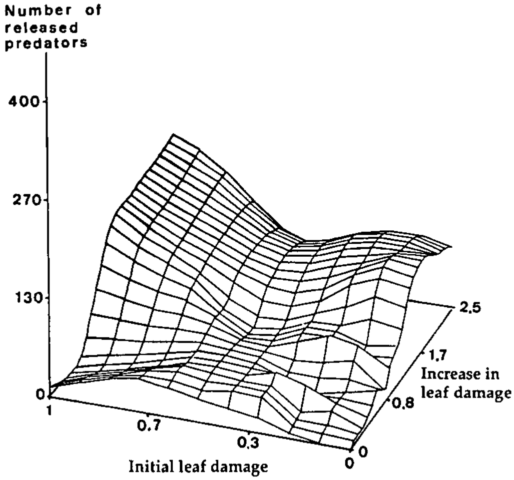

FIG. 2
Numbers of *P. persimilis* released per tomato plant in culture 2, related to the initial values of the Mean Leaf Damage Index (init. MLDI) and to the differences between the final and the initial values of the MLDI (△ MLDI), during the first increase of the prey populations.

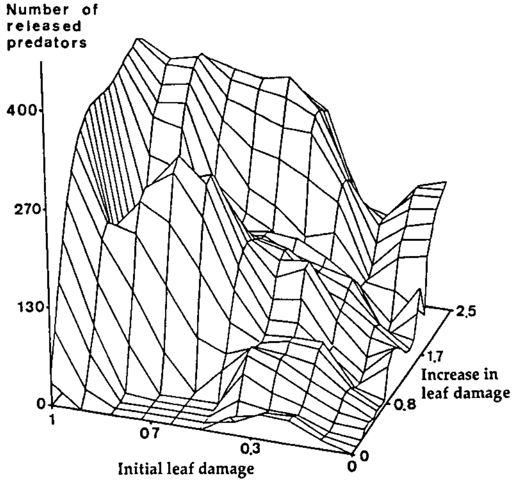

FIG. 3
Numbers of *P. persimilis* released per tomato plant in culture 5, related to the initial values of the Mean Leaf Damage Index (init. MLDI) and to the differences between the final and the initial values of the MLDI (△ MLDI), during the first increase of the prey populations.

TABLE II
Parameters and statistics of the Taylor's regression measuring the aggregation of the spider mites on the tomato plants

Culture	n	a	SE	b	SE	r^2
1	7	3.69**	0.91	1.93a	0.25	0.99
2	20	−0.76*	0.68	2.16b	0.10	0.96
3	8	2.98**	0.54	1.78a	0.07	0.99
4	13	5.10**	0.29	1.71a	0.05	0.99
5	23	0.75*	0.53	2.02b	0.07	0.97

SE: standard error.
* : not significantly $\neq 0$ ($P<0.05$).
**: significantly >1 ($P<0.05$).
Values followed by the same letter are not significantly different ($P<0.05$).

remaining spider mites and independent of the plant damage.

Crop 5: First increasing phase: At the time of the first release (30 April, 1990) the degree of plant damage was 0.3 (s = 0.3; plants with 22–23 leaves), and after five weeks it had reached a maximum level of 1.3 (s = 0.8). More predators were released onto the fifth crop than onto the second: 19,300 predators per 100 m^2 (Figure 3).

Second increasing phase: In this phase the predatory mites did not establish, even after five weeks during which plant damage increased. For some unknown reason the predators began to die in large numbers within a few days of being released. An effective establishment occurred later when the MLDI reached 2.0 (s = 0.9). Two weeks later plant damage stabilized, and the mean maximum damage recorded was MLDI = 2.4 (s = 0.7). The figure obtained by plotting damage against the numbers of predators released (28 500 per 100 m^2) shows a very irregular relationship.

Thus the MLDI can only in the case of the first increasing phase of the spider mite be used to determine the numbers of predatory mites that should be introduced. The MLDI evaluation of the number of predatory mites required proved more efficient on young plants with fewer leaves.

In the other three crops, a rapid and uncontrollable situation developed (Figure 1). In the third crop, 6 200 predators per 100 m^2 were introduced between 30 August and 13 September without effect, while in the fourth crop, approximately 37 000 predators per 100 m^2 were introduced between 20 March and 5 June 1991 also without effect. On 20 June 1991, chemical control of the spider mites was finally chosen.

Aggregation of the spider mites

The 'b' parameters for each crop revealed an aggregative distribution of the spider mite. Significant differences between their values were nevertheless detected by covariance analysis (Table II). Aggregation of the phytophagous mites on tomato plants increased more intensely with the mean number of individuals in the second and fifth crops than in the other three. As expected, both crops were characterized by a more successful establishment of predatory mites. The aggregation pattern of the spider mite seems thus to have been modified by the predator.

DISCUSSION

Biological control of spider mites on tomatoes through the use of predatory mites (*Phytoseiulus persimilis*) was difficult to achieve, and in fact failed in three of the five cultures. In the two crops where establishment was substantially greater numbers of predators were required than suggested by Havelka and Kindlmann (1984) and Hussey and Scopes (1985). This may be partially due to the facts that these authors released predatory mites on younger tomatoes at the first signs of spider mite attacks (MLDI <0.2), and because their experiments ran for a shorter time than ours.

It appears that the predators, after having settled in a crop and having achieved control of the spider mites, were unable to control further prey upsurges. An analysis of the foliage reveals that the predatory mites had all but disappeared from the crop. Thus the development of predator numbers followed a cyclical pattern because of successive establishment and elimination of the mite. During some periods, dead predators were found on the foliage in significant numbers only a week after their release.

Unfavourable environmental abiotic conditions might have been responsible for high rates of mortality. Temperature and relative humidity are important factors in *Phytoseiulus persimilis* mortality and development (Stenseth, 1979; Sabelis, 1981). The failure to control the spider mites in the third and fourth crops occurred between late April and mid-September. This failure is possibly related to the unfavourable changes in the abiotic conditions at this time of the year. The failure of the first crop might be attributed to an initial release of too few predators. In the fifth crop effective control of the pest during spring and summer is probably due to the more stable temperatures and relative humidities in the glasshouse (fog system). On roses, however, *P. persimilis* mites have successfully controlled *T. urticae* despite high temperatures (Gough, 1991), which suggests that the plant itself may be a factor in establishing an equilibrium between predatory and prey mites.

The disappearance of the predator might also be explained by the high functional response and the specificity of *Phytoseiulus persimilis* (Hance, 1988). This particular predatory mite aggregates in the most dense colonies of its prey (Sabelis, 1981; Eveleigh and Chant, 1980; Bernstein, 1984) and tends to remain in the colony until almost all of the prey has been destroyed. This leads to a rapid suppression of local prey populations. Once prey numbers have been sharply reduced, the predator either starves or leaves the plant in search of new prey patches (Sabelis, 1981). This may also explain why in our experiment populations of spider mites were more aggregated when biological control was more effective. Nothing in our experiments was done to preserve this more aggregated pattern of prey which was probably created by interaction between the prey and the predator. On the contrary, predators were released uniformly on each plant to provide predator individuals in each prey patch, and consequently, the population of the pest mites was probably reduced sharply. This is confirmed by the low variance values in the case of low spider mite numbers (Table II).

The general instability of the prey-predator interaction observed in our crops was probably due to intensive and regular releases of the predator on all the tomato plants. It is well known that an homogeneous environment causes synchrony of local demographic fluctuations in phythophagous and predatory mites, which in turn results in a general instability (Nachman, 1988). Thus more local and heterogeneous predator releases must be tested as they might maintain variability in prey per plant numbers, which seems to be important for establishing a stable prey-predator system. The influence of the abiotic conditions on the settlement of the predator on tomato plants must also be investigated.

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