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We developed and validated a management plan for *Tetranychus urticae* in strawberries, based on the natural control exerted by *Neoseiulus californicus* and on acaricide applications made only when necessary. The plan has two components: a sampling protocol and a decision chart. Systematic presence–absence sampling of active *T. urticae* and *N. californicus* was used to predict prey and predator densities relying only on the proportion of *T. urticae*-infested leaflets, once the occurrence of the predator was detected in at least one of them. The decision chart, which was constructed taking into account the pest and predator densities and the pest's rate of increase, determines the range in the proportion of *T. urticae*-infested leaflets that will require different actions: to use selective acaricides and re-check at 7 days, to take no action but re-check at 7 days, or to take no action but re-check at 14 days. The management plan was potentially effective and feasible, showing that natural populations of *N. californicus* can consistently exert strong top-down suppression of *T. urticae*. Thus, *N. californicus* is a promising candidate for conservation biological control.

Keywords: biological control; conservation; pest management plan; sampling

1. Introduction

The two-spotted spider mite, *Tetranychus urticae* Koch, is a common pest affecting commercial strawberry farms in several countries. Predatory mites, *Phytoseiulus persimilis* Athias-Henriot, *Neoseiulus fallacis* (Garman) and *N. californicus* (McGregor) are used in the biological control of *T. urticae*, mainly by augmentative releases (Hussey and Scopes 1985; Waite 1988; Raworth 1990; Zalom et al. 1990; Steiner and Bjørnson 1996; Coop et al. 1997; Steinberg et al. 1999; Rhodes and Liburd 2006; Fitzgerald et al. 2007; Gerson and Weintraub 2007; Sato et al. 2007; Palevsky et al. 2008).

Neoseiulus californicus is the main established predator of *T. urticae* in commercial strawberry crops in La Plata, Buenos Aires, Argentina (Greco et al. 1999). In this region, the predator is able not only to detect leaflets supporting low densities of *T urticae* (Greco et al. 1999), but also to limit the rate of prey population increase, depending on the initial prey–predator ratio. These characteristics suggest this predator is a promising agent for biological control of *T. urticae* in La Plata (Greco et al. 2005). Notwithstanding, the application of acaricides (abamectin) on a scheduled basis is the current control method for the two-spotted spider mite in conventional strawberry production, despite this practice having a negative effect on *N. californicus* populations (Sato et al. 2002). Many growers have started to reduce the use of pesticides, either for economic reasons or due to an interest in obtaining pesticide-free products. Although augmentative releases of the predator could be a feasible strategy, *N. californicus* is not yet commercially available in the Argentinian market. Therefore, conservation biological control seems to be a worthwhile alternative to explore in view of the growers' need to reduce pesticide inputs in Argentina. Indeed, naturally occurring *N californicus*, conserved by selective use of pesticides, was sufficient for the control of *T. urticae* on strawberry crops in Spain (García Mari et al. 1991).

Greco et al. (2004) developed a systematic presence–absence sampling regime for *T. urticae* and *N. californicus* in strawberry based on the high synchrony and spatial coincidence between predator and prey (Greco et al. 1999). The advantage of this sampling regime is the possibility of predicting prey and predator densities relying on the proportion of leaflets with only one of them (the prey), once the presence of the predator has been detected. Additionally, Greco et al. (2005) have used laboratory and field data to predict pest density at weekly intervals, taking into account the pest–predator ratio, comparing predicted densities with the economic threshold level (ETL).

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On the basis of previous knowledge, we have developed and validated a management plan for *T. urticae* in strawberry founded on the natural occurrence of *N. californicus*. This paper reports our findings.

2. Materials and Methods

2.1. *Development of the* T. urticae *management plan*

The management plan has two components: a sampling protocol and a decision chart. The sampling protocol consists of systematic presence–absence sampling (Greco et al. 2004). The main advantage of this is the possibility of predicting prey and predator densities (active mites: larvae, nymphs and adults/leaflet) relying only on the proportion of *T. urticae*-infested leaflets, once the presence of the predator has been detected on at least one leaflet. Presence of mites (*T. urticae* and *N. californicus*) is assessed using a pocket lens ($\times 10$ magnification), and leaflets with *T. urticae* are counted. The presence–absence sampling indicates that one leaflet from a mature leaf should be collected in each row at 10-m intervals (10 footsteps, each of approximately 1 m). To simplify the calculation of the proportion of *T. urticae*-infested leaflets, the sampling protocol prescribes collecting and observing 100 leaflets in each monitoring period.

The decision chart was constructed taking into account the following: (1) the pest and predator densities indicated by the proportion of *T urticae*-infested leaflets reported by Greco et al. (2004) (Table 1); (2) the daily rate of increase of *T. urticae* based on the results of Greco et al. (2005). It is calculated from *T. urticae* density at 7-day intervals for initial densities of 5, 10, 15 and 20 active *T. urticae* mites per leaflet, when the predator is absent and present. We assumed exponential growth of the *T. urticae* population, and the per-capita daily rate of increase (r) was calculated as:

$$r = \ln(N_t/N_0)/\Delta t,$$

where N_0 and N_t are the initial and final *T. urticae* densities, respectively, and Δt is the interval of 7 days.

Then, from initial *T. urticae* density (N_0) corresponding to the different proportion of *T. urticae*-infested leaflets, as indicated in Table 1, we predicted the number of days (t) for *T. urticae* to reach the ETL as a function of the daily rates of increase:

$$t = \ln(\mathrm{ETL}/N_0)/r,$$

where the ETL is considered as 50 active *T. urticae* per strawberry leaflet (Wyman et al. 1979).

The values of r in the above equation were selected for each proportion of *T. urticae*-infested leaflets with absence and presence of predators. For example, the rate of increase of *T. urticae* when the predator was absent, was calculated as the average of those rates determined by Greco et al. (2005) corresponding to the pest densities in the range from the mean to the upper limit, matching to each proportion of *T. urticae*-infested leaflets (Greco et al. 2004). When the predator

Table 1. Density (mean number of larvae, nymphs and adults per leaflet) of *Tetranychus urticae* and *Neoseiulus californicus*, and 90% confidence limits, given the observed proportion (p) of leaflets infested with *T. urticae*, predicted by the models *T. urticae* density: $\hat{\mu}Tu = \exp\ (2.78 + 1.31\ \ln\ [-\ln\ p])$ and *N. californicus* density: $\hat{\mu}Nc = \exp\ (-0.04 + 0.76\ \ln\ [-\ln\ p])$ according to presence–absence sampling (Greco et al. 2004), and the pest–predator ratio.

Proportion of leaflets infested with *T. urticae*	Lower limit of *T. urticae* density	*T. urticae* density	Upper limit of *T. urticae* density	Lower limit for *N. californicus* density	*N. californicus* density	Upper limit of *N. californicus* density	*T. urticae*/ *N. californicus* ratio
0.95	14.59	67.52	312.56	0.27	2.21	17.77	30.55
0.90	10.50	47.87	218.31	0.23	1.81	14.31	26.45
0.85	8.21	37.17	168.19	0.2	1.56	12.22	23.83
0.80	6.66	29.98	134.98	0.18	1.38	10.69	21.72
0.75	5.50	24.67	110.66	0.16	1.23	9.48	20.06
0.70	4.58	20.51	91.79	0.14	1.11	8.47	18.48
0.65	3.84	17.15	76.60	0.13	1.00	7.59	17.15
0.60	3.22	14.36	64.04	0.12	0.90	6.82	15.95
0.55	2.69	11.99	53.46	0.11	0.81	6.11	14.801
0.50	2.24	9.97	44.44	0.10	0.73	5.47	13.66
0.45	1.84	8.22	36.66	0.09	0.65	4.87	12.64
0.40	1.50	6.69	29.90	0.08	0.58	4.31	11.53
0.35	1.19	5.35	24.01	0.07	0.51	3.78	10.49
0.30	0.93	4.18	18.86	0.06	0.44	3.27	9.50
0.25	0.69	3.16	14.36	0.05	0.37	2.78	8.54
0.20	0.49	2.27	10.45	0.04	0.31	2.30	7.32
0.15	0.32	1.50	7.08	0.03	0.24	1.82	6.25
0.10	0.17	0.85	4.23	0.02	0.17	1.33	5.00
0.05	0.06	0.33	1.91	0.01	0.10	0.82	3.30

was present, we proceeded in the same way but took into account the prey–predator ratio.

Analysing all this information, we constructed the decision chart, determining the range in the proportions of *T. urticae*-infested leaflets that would require different actions. The time spent in monitoring was also taken into account to evaluate the feasibility of the plan.

2.2. Evaluation of the effectiveness of the management plan

The management plan was evaluated from June to December 2006 and from October 2008 to January 2009, comparing *T. urticae* and *N. californicus* densities with those from other commercial crops under different management practices. A total of 26 plots, approximately 1200 m^2 each (20 beds of 0.70 m width by 50 m long, and 0.5 m between beds), was monitored using the systematic presence–absence sampling. By checking all leaflets *in situ* with the pocket magnifier, we recorded the number of *T. urticae*-infested leaflets; by consulting the decision chart, the corresponding action was decided.

During June–December 2006 the study plots were selected from crops with the following management practices:

- Second year crops, with infrequent chemical applications during the previous year, where the management plan was applied (SYMP, Second Year Management Plan) (five plots).
- First year crops where the management plan was applied (FYMP, First Year Management Plan) (six plots).
- Second year crops where scheduled chemical applications were made early, with no chemical applications from November until the end of the season (CAES, Chemical Applications Early Season) (three plots).
- Second year crops where scheduled (weekly) chemical applications were made throughout the season (CAAS, Chemical Applications All Season) (three plots).

During October 2008 to January 2009, four SYMP, two CAES and three CAAS plots were compared.

The commercial strawberry crops (Aromas), cultivated under plastic tunnels, were located in horticultural farms in La Plata, Buenos Aires, Argentina (38°52′S, 57°59′W). Irrigation and soil management were standard for the region. Granulated fertilizer was applied to the soil 20 days before planting, with the following composition: total nitrogen (N) 15.0% (ammoniacal N, 8.89%, nitrate N, 6.11%), assimilable phosphorus (P_2O_5) 15.0% and water-soluble potassium (K_2O) 15.0%. Methyl bromide was used to disinfect the soil. The beds were covered with black polyethylene mulch and irrigated by drip. In all sites, the fungicide Benosem 50 PM® (benomyl 50%) was used weekly. In SYMP and FYMP plots the acaricide New Mectin® (abamectin 1.8%), was applied as required by the Management Plan, and insecticides were not applied because densities of other pests such as thrips, whiteflies and aphids were low. In CAAS and CAES plots, New Mectin® and insecticides, Lannate® (methomyl 90%), Metamidofos 60 Alecy (metamidophos 60%) and Tetranyl® (dicofol 21% + tetradiphon 7.5%) were applied on a weekly basis throughout the season.

Simultaneously, density estimates of both species on the same leaflets were made, counting all active mites by stereomicroscope (× 20) and expressed as mean number of active mites/leaflet/date/plot. Mean *T. urticae* and *N. californicus* densities per plot, were compared among treatments by one-way repeated-measures analysis of variance (ANOVA). Previously, Mauchley's Sphericity Test was used to test the assumption of circularity. When this assumption could not be met, the degrees of freedom of the *F*-statistic were adjusted following the Greenhouse–Geisser method (Scheiner and Gurevitch 2001). To meet the requirements necessary for the ANOVA models (variance homogeneity and normal distribution) abundance data were log-transformed. Multiple comparisons were made with the Bonferroni test (Zar, 1996).

2.3. Precision of the presence-absence systematic sampling

The error stemming from collecting a number greater or less than the 100 leaflets (hypothesized population mean) required by the systematic presence–absence sampling was evaluated by a two-tailed Student's *t*-test for differences between a population mean and the hypothesized population mean (Zar, 1996).

The number of leaflets with *T. urticae* observed in the field, using a pocket lens at × 10 magnification, was checked in the laboratory under a stereomicroscope. Pearson product-moment correlation coefficients were calculated to test the relationship between both estimates. As our expectation was that field and laboratory estimates would be as similar as possible, we calculated the regression equation following the Bartlett's three-group method (Sokal and Rohlf 1995) between laboratory estimates (as variable x) and field estimates (as variable y) to evaluate the departure of the slope and the intercept from 1 and 0, respectively.

The goodness-of-fit between estimates of population densities by the proportion of leaflets with *T. urticae* using the presence–absence sampling (see equations in Table 1) and the estimates on the same leaves under binocular microscope was evaluated using the Pearson product-moment correlation coefficient and the mean square error.

3. Results

3.1. *The* T. urticae *management plan*

The number of days required for *T. urticae* mites to reach the ETL at different initial *T. urticae* densities (estimated from proportions of *T. urticae*-infested leaflets), and the corresponding daily rate of increase of *T. urticae* (Table 2), was quite variable (Figure 1). For example, for 0.25 leaflets infested with *T. urticae* and absence of predators, the mean pest density was 3.16 and the upper limit was 14.36 (Table 1), so the rate of increase used was the mean of those corresponding to the range of densities 3.16–14.36 (5, 10 and 15 initial *T. urticae* densities for pest–predator ratio = 0; Table 2), which was $r = 0.402$ individuals/individual/day (Figure 1). When predators were present, the pest–predator ratio was taken into account, and for 0.25 leaflets infested with *T. urticae* the rate of increase used ($r = 0.172$ individuals/individual/day) (Figure 1) was the mean of those corresponding to 5, 10 and 15 initial *T. urticae* densities, and a *T urticae* to *N. californicus* ratio = 7.5 (Table 2).

The number of days required for *T. urticae* mites to reach the ETL, if the predator was absent and for the proportions of leaflets infested with *T. urticae* ranging from 0.05 to 0.25, was between 12.71 and 6.87 days (Figure 1), so no acaricide applications or a monitoring at 7 days should be necessary. At proportions of leaflets infested with *T. urticae* higher than 0.30, the pest should reach the ETL in less than 7 days (Figure 1), so the acaricide applications will be required and then monitoring done at 7 days. On the other hand, if the predator is present and the proportions of *T. urticae*-infested leaflets are from 0.05 to 0.25, the pest will reach the ETL between 46.06 and 17.15 days (Figure 1), so the appropiate action should be to not apply acaricides and to monitor at 14 days. For proportions of *T. urticae*-infested leaflets between 0.30 and 0.45, the pest will reach the ETL between 12.06 and 7.88 days (Figure 1), so the suitable action should be to not apply acaricides and to monitor at 7 days. If the proportion is 0.50 or more, the pest will reach the ETL in less than 7 days (Figure 1), so acaricide applications should be necessary and then monitoring should be done at 7 days.

Based on these results, the decision chart (Table 3) was constructed looking for simplicity and minimization of risk to the growers. As all calculations were based on proportions, the sampling protocol indicates collecting and observing 100 leaflets in each monitoring, so the actions are based directly on the number of *T. urticae*-infested leaflets. To minimize the risk, the suggested monitoring intervals were equal or lower than the estimated value corresponding to the higher *T. urticae* density, and adjusted to weekly intervals (i.e. when the predator was present and the proportions of leaflet infested with *T. urticae* were from 0.05 to 0.25, the pest will reach the ETL between 46.06 and 17.15 days, so the monitoring was to be at14 days).

The decision chart indicates three possible options in relation to the number of *T. urticae*-infested leaflets:

Table 2. Daily rates of increase of *Tetranychus urticae* calculated from the mean numbers of active *T. urticae* per leaflet, after 7 days, for different initial pest densities and initial pest–predator ratios, as reported in Greco et al. (2005).

Initial pest density	Pest–predator ratio	Daily rate of increase of *T. urticae*
5	0	0.395
5	15	0.403
5	10	0.408
5	7.5	0.211
5	5	0.119
10	0	0.408
10	15	0.287
10	10	0.188
10	7.5	0.111
10	5	0.121
15	0	0.403
15	15	0.251
15	10	0.288
15	7.5	0.195
15	5	0.033
20	0	0.454
20	5	0.128

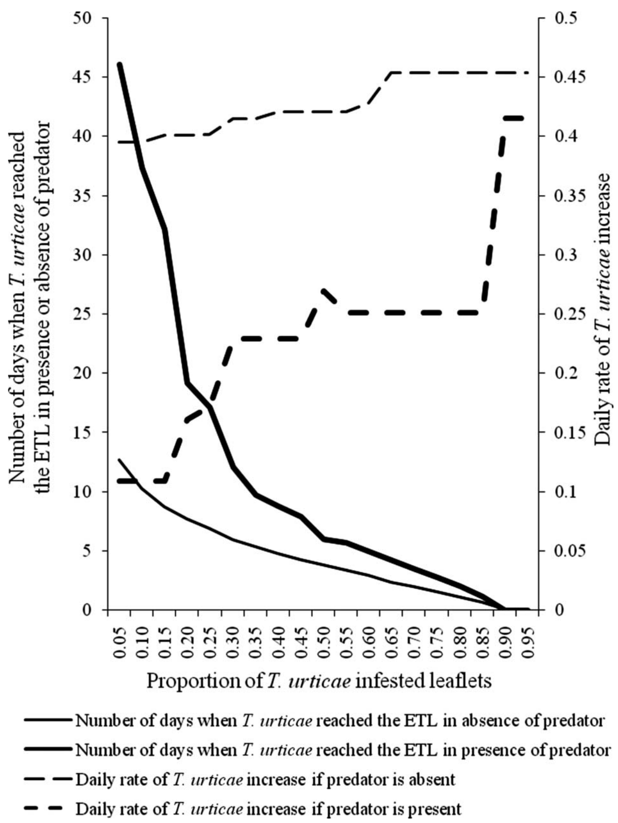

Figure 1. Daily rate of increase of *Tetranychus urticae* and the number of days required for the mites to reach the economic threshold level (ETL) at different initial *T. urticae* densities (estimated from proportions of *T. urticae*-infested leaflets) in the presence or the absence of predator.

Table 3. Decision chart for the management plan for *Tetranychus urticae* in strawberries, using *Neoseiulus californicus* as predator.

Number of leaflets with *T. urticae*	Action	
	Predator absent	Predator present
Less than 30	No acaricide application and re-check at 7 d	No acaricide application and re-check at 14 d
Between 30 and 50	Acaricide application and re-check at 7 d	No acaricide application and re-check at 7 d
50 or more	Acaricide application and re-check at 7 d	Acaricide application and re-check at 7 d

(1) to use selective acaricides and re-check at 7 days, (2) to take no action but re-check at 7 days, and (3) to take no action but re-check at 14 days.

In summary, the management plan consists of the following steps: (1) Collect 100 leaflets individually, at 10-footstep intervals. (2) Examine the underside of each leaflet with a pocket magnifier to determine the presence of two-spotted spider mites and then count the number of infested leaflets. (3) Check leaflets for the presence of predators until at least one predator is detected (if no predator is detected, all leaflets have to be checked). (4) Consult the decision chart.

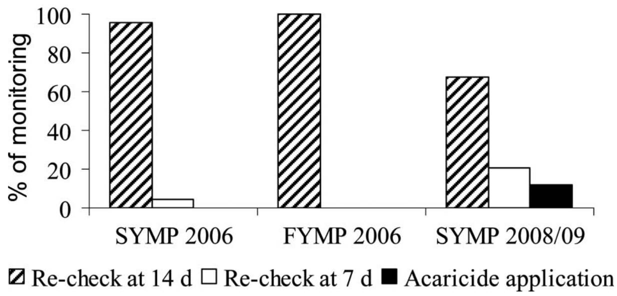

Figure 2. Percentage of monitoring for which each type of recommendation, based on the action chart, was suggested in SYMP (Second Year Management Plan) and FYMP (First Year Management Plan) strawberry plots.

3.2. *Evaluation of the effectiveness of the management plan*

Figure 2 shows the percentages of each type of action indicated by the decision chart. In both seasons most indications were "no acaricide application and re-check at 14 d", and indeed densities estimated by the stereomicroscope in the laboratory corroborated it. In all plots *T. urticae* density remained under the ETL (Figures 3 and 4). The recommendation "acaricide application and re-check at 7 d" was indicated four times in 2008/09, in three of four plots (Figure 4, SYMP: 02-Oct-08 and 16-Oct-08). However, when densities were checked in the laboratory, in three cases (once per plot) the indicated action could have been avoided. The management plan allowed us to reduce acaricide applications by more than 90%.

Following the management plan during June–December 2006 the mean number of monitorings per plot was 14.2 (standard deviation [SD] = 1.923) and 15.5 (SD = 0.548) in SYMP and FYMP, respectively. During 2008 to January 2009 the mean number of monitorings was 8.6 (SD = 1.516). The time spent for each sampling was 14.77 $\pm$ 1.96 min ($n = 30$) to collect the leaflets and 28.76 $\pm$ 6.30 min ($n = 37$) for on-site inspections, during each sampling.

During June–December 2006, the mean number of *T. urticae* mites per leaflet differed among treatments and over time (Table 4). In addition, there was significant interaction between treatments and time of monitoring. SYMP and CAAS exhibited similar low densities of *T. urticae*. In CAES, *T. urticae* was more abundant in November–December; this was the only site in which the mite reached densities close to the ETL (Figure 3). In FYMP plots, the maximum value was similar to that for CAAS, but was recorded later in the spring, probably because these were first-year crops and there could have been some delay in mite colonization. In CAAS, growers began to apply acaricides when the *T. urticae* populations started to increase during autumn. Densities decreased and remained very low during winter but with a small increase in spring. Post-hoc comparisons of means indicated that the density of *T. urticae* was higher in CAES than in the other plots in November–December ($P < 0.05$).

Densities of *N. californicus* did not differ either among treatments or over time (Table 5). The predator was present at all times in SYMP, while in CAAS it was recorded only at the beginning of crop growth (autumn). In FYMP and CAES it appeared late in the season (Figure 3).

During October 2008 to January 2009 *T. urticae* densities differed significantly between treatments and over time. Also, there was a significant interaction between these factors (Table 4, Figure 4). In SYMP, density of two-spotted spider mites was higher than in CAES and CAAS, but only on the first monitoring date. In CAES, densities were the highest and exhibited a similar pattern to that of the previous season.

Neoseiulus californicus was present throughout the entire sampling period in all treatments (Figure 4). In SYMP, the highest densities occurred at early season,

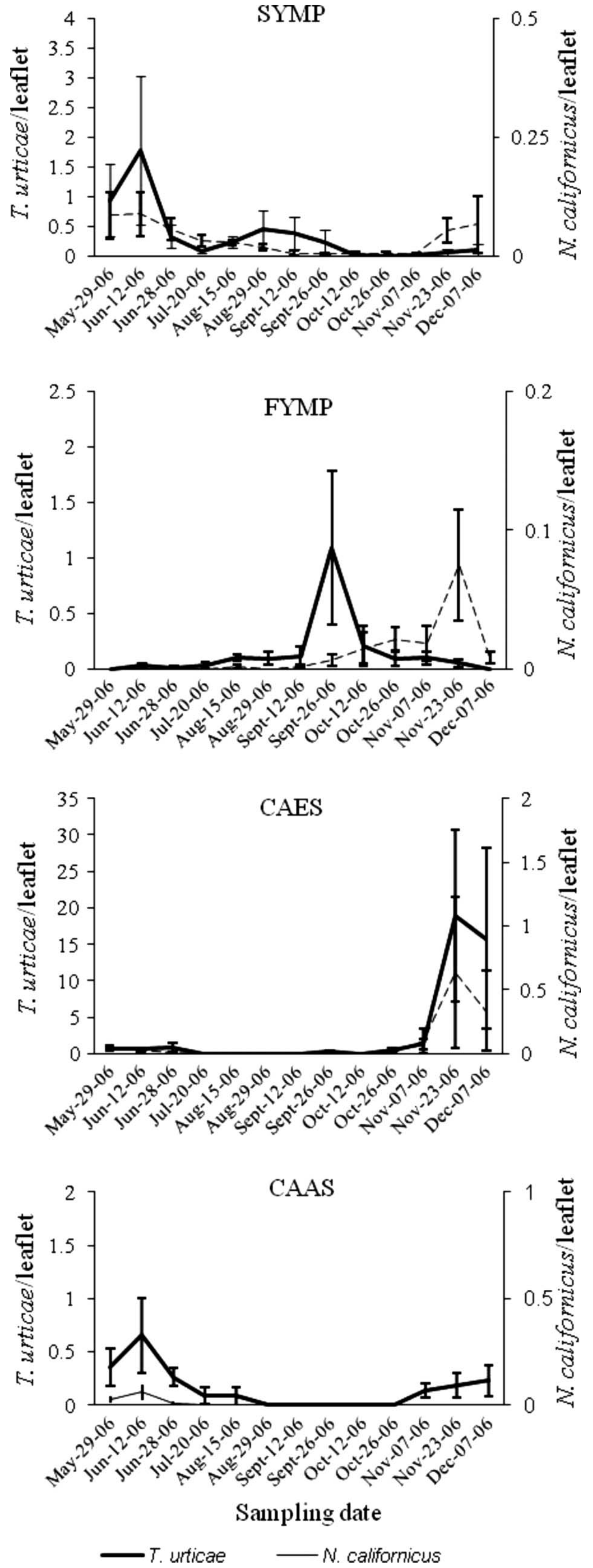

Figure 3. Means of active *Tetranychus urticae* and *Neoseiulus californicus* per leaflet recorded from June to December 2006. SYMP (Second Year Management Plan), FYMP (First Year Management Plan), CAES (Chemical Applications Early Season), CAAS (Chemical Applications All Season).

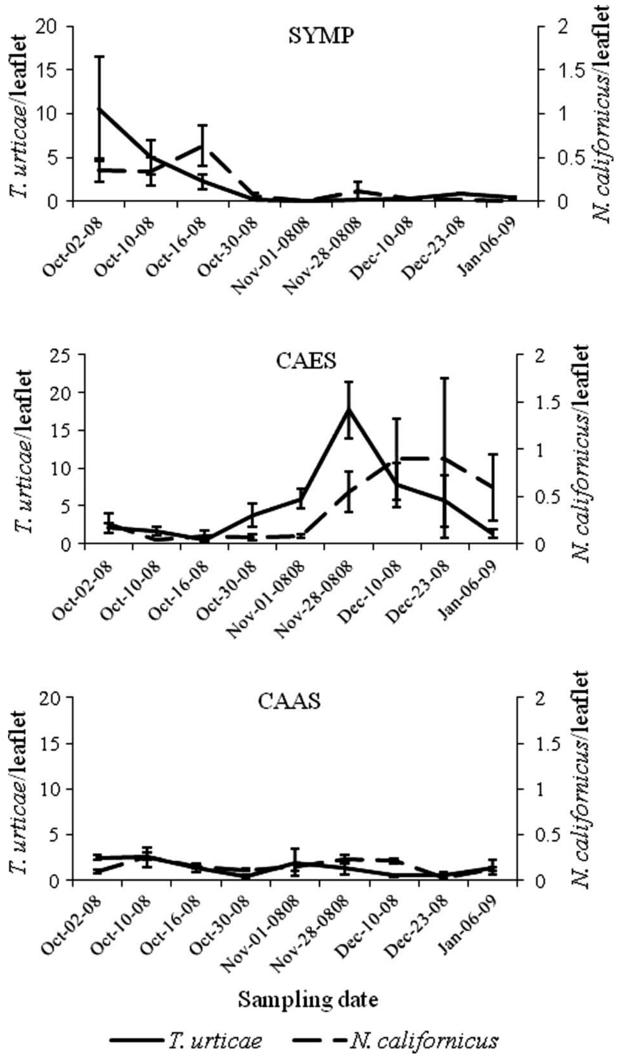

Figure 4. Means of active *Tetranychus urticae* and *Neoseiulus californicus* per leaflet recorded from October 2008 to January 2009. SYMP (Second Year Management Plan), CAES (Chemical Applications Early Season), CAAS (Chemical Applications All Season).

while in CAES these took place in November and December in agreement with the higher prey abundance.

3.3. Precision of the presence–absence systematic sampling component.

The mean number of leaflets collected per sampling, 99.423 (SD = 8.636; n = 300), was not significantly different from 100 ($t = -1.156$; df = 299; $P = 0.248$).

The number of *T. urticae*-infested leaflets detected in the field using a pocket magnifier and the number recorded using the stereomicroscope were positively correlated ($r = 0.975$; $t = 73.301$; $n = 279$; $P < 0.001$), and Bartlett's method ($y = 1.012x - 0.119$; $r^2 = 0.951$) suggesting that the slope and the intercept were close to 1 and 0, respectively.

Table 4. Result of repeated-measures ANOVA for the comparison of the mean number of active *Tetranychus urticae*/leaflet/date/plot among treatments: SYMP (Second Year Management Plan), FYMP (First Year Management Plan), CAES (Chemical Applications Early Season) and CAAS (Chemical Applications All Season).

Source of variation	df effect	df error	*F*	*P*-value	df G-G effect[a]	df G-G error[a]	Adj. *P*-value
2005/06							
Treatments	3	13	7.667	0.003			
Time	13	156	8.782	0.000	3.179	41.334	0.000
Interaction	36	156	8.296	0.000	9.536	41.334	0.000
2008/09							
Treatments	2	7	12.778	0.005			
Time	8	56	3.409	0.003			
Interaction	16	56	6.549	0.000			

[a]df G-G: adjusted degrees of freedom by Greenhouse–Geisser Test ($\varepsilon = 0.265$).

Table 5. Result of repeated-measures ANOVA for the comparison of the mean number of active *Neoseiulus californicus*/leaflet/date/plot among treatments: SYMP (Second Year Management Plan), FYMP (First Year Management Plan), CAES (Chemical Applications Early Season) and CAAS (Chemical Applications All Season).

Source of variation	df effect	df error	*F*	*P*-value	df G-G effect[a]	df G-G error[a]	Adj. *P*-value
2005/06							
Treatments	3	13	1.431	0.278			
Time	12	156	3.162	0.000	1.28	16.65	0.086
Interaction	36	156	1.710	0.013	3.84	16.65	0.196
2008/09							
Treatments	2	7	1.504	0.286			
Time	8	56	1.239	0.294			
Interaction	16	56	2.939	0.001			

[a]df G-G: Adjusted Degrees of Freedom by Greenhouse–Geisser Test ($\varepsilon = 0.106$).

The *T. urticae* densities recorded under the stereomicroscope were correlated with those predicted by the presence–absence model (2006: $r = 0.749$, $t = 10.790$, $n = 93$, $P < 0.001$, mean square error $= 16.846$; 2008–09: $r = 0.609$, $t = 6.475$, $n = 74$, $P < 0.001$, mean square error $= 152.811$). Seventy six and eighty nine percent of the estimates in 2006 and 2008/09, respectively, were below the mean predicted by the presence–absence model (Figure 5). *Neoseiulus californicus* estimates recorded using the stereomicroscope were also correlated with those obtained using the proportion of *T. urticae*-infested leaflets (presence–absence model) (2006: $r = 0.614$, $t = 7.378$, $n = 93$, $P < 0.001$, mean square error $= 0.060$; 2008–09: $r = 0.584$, $t = 6.108$, $n = 74$, $P < 0.001$, mean square error $= 0.356$). In this case, 92.5% of the estimates in 2006 and 86.5% in 2008/09 were below the mean (Figure 6).

4. Discussion

Our results suggest that the management plan developed for *T. urticae* in strawberry is effective and easy for growers to implement. Natural populations of *N. californicus* can consistently exert strong top-down suppression of *T. urticae*, making this predator a promising candidate for conservation biological control. The management plan could also be implemented in other cultivars, although with caution. Preliminary results suggest that *T. urticae* performs similarly on Camarosa, Diamante, Sabrosa, Selva, Sweet Charly, KP, Whitney and Festival (unpublished), but the predator's performance on these cultivars is not known.

In plots where the management plan was implemented, acaricide applications were occasionally necessary, and pest densities remained low and similar to those recorded in the plots subjected to conventional management. Furthermore, it was observed that in plots receiving conventional acaricide applications until November and then stopped (CAES), *T. urticae* increased notably in both seasons. *Neoseiulus californicus* densities also increased although with some delay in relation to prey, still markedly reducing pest density. In plots where the management plan was implemented the indications of the decision chart were different between plots of second and first years strawberry crops. In FYMP, the indication was always "no application and re-check at 14 d", while in SYMP plots indications were "no application and re-check at 7 d" and "application and re-check at 7 d". We attribute these differences to *T. urticae*'s recent colonization of FYMP, exhibiting lower densities than SYMP where the population of *T. urticae* was already established.

The management plan indicated four acaricide applications, in 2008/09. However, when pest densities were verified using the stereomicroscope, a field

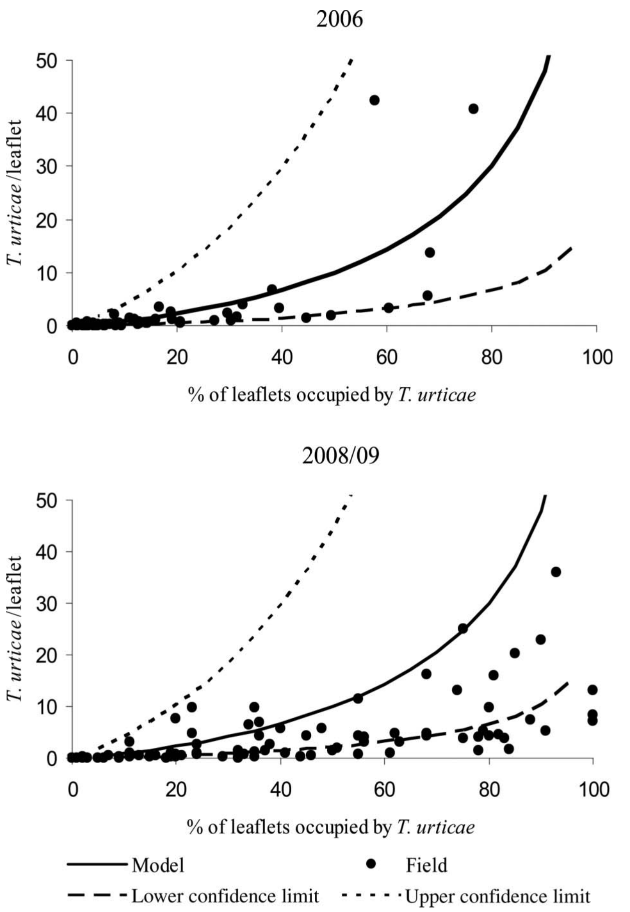

Figure 5. Relationship between *Tetranychus urticae* density and percentage of leaflets with *T. urticae* in 2006 and 2008/09. Unbroken and dotted lines indicate densities and confidence limits, respectively, estimated by systematic presence-absence sampling (Greco et al. 2004).

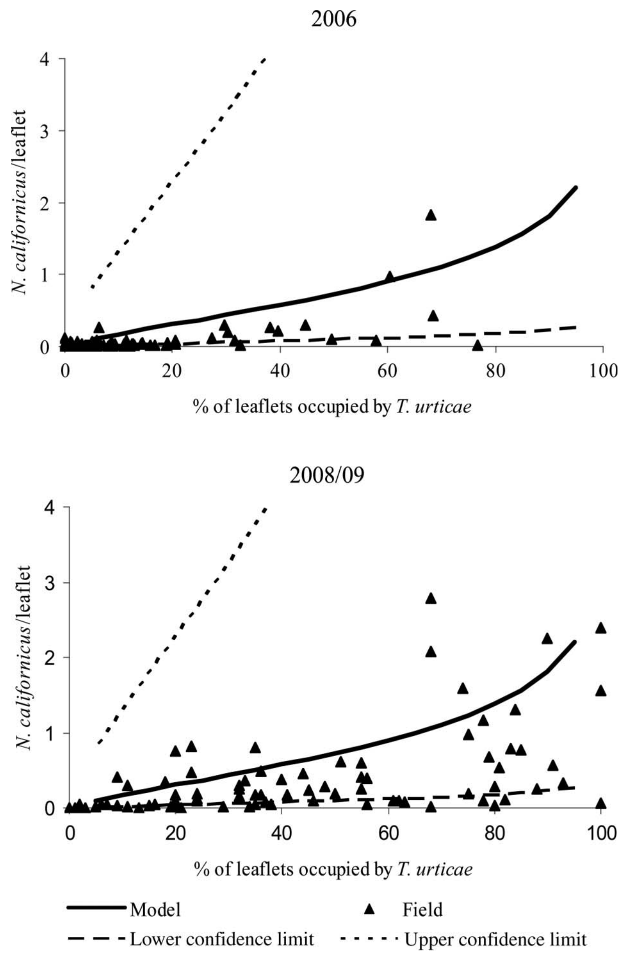

Figure 6. Relationship between *Neoseiulus californicus* density and percentage of leaflets with *T. urticae* in 2006 and 2008/09. Unbroken and dotted lines indicate densities and confidence limits, respectively, estimated by systematic presence–absence sampling (Greco et al. 2004).

overestimation was found in three cases, indicating a wrong recommendation. The density of *T. urticae* and *N. californicus* was generally overestimated by the presence–absence sampling method. We take these cases to correspond to the end of a typical predator–prey interaction where a high proportion of leaflets was occupied, but with few active mites in each one. Moreover, remains of dead mites could have been confused with live mites, contributing to the density overestimation by means of presence–absence sampling. The management plan might result in a few unnecessary acaricide applications, but it will not increase the risk of crop yield loss, which would be the case if the pest were underestimated. On the contrary, the overestimation of *N. californicus* in the field could be more serious because it would be assumed that there were more predators than those that actually were present. Due to their high mobility, the predators may have abandoned the leaves while the samples were taken to the laboratory, increasing the error of the estimation. This could explain the differences between the density values for *N. californicus* estimated by the method of presence–absence of *T. urticae* and those observed under stereomicroscope. Indeed, in this study *N. californicus* was able to maintain the populations of *T. urticae* at a low density throughout two growing seasons.

In contrast to other parts of the world, *N. californicus* is not commercially produced in Argentina; growers therefore cannot implement currently augmentative releases of this predator. Our management plan takes advantage of the natural occurrence of this predator and proposes the use of more selective and fewer applications of acaricides. Augmentative releases of this predator could be one way of improving the management plan, if mass-rearing of *N. californicus* were to become available in Argentina, and they could replace acaricide applications. Moreover, conservation biological control of this natural enemy by means of habitat manipulation outside of the crop, providing necessary resources such as shelter and alternative food for survival (Ferro and McNeil 1998), could enhance its performance and would be worth investigating.

The potential of *N. californicus* as a biological control agent has been widely documented (Sabelis and Janssen 1994; McMurtry and Croft 1997; Rhodes and Liburd 2006; Sato et al. 2007). The output of our management plan model is congruent with the results of field experiments by Sato et al. (2007), which indicate that this predator is capable of maintaining low *T. urticae* densities at appropiate relative prey–predator ratios. Moreover, our results based on comparable predator–prey ratios (Greco et al. 2005) were similar to those recorded in Florida (Fraulo and Liburd 2007). Fraulo and Liburd (2007) observed that releases at the appropriate ratio of between 1:5 and 1:10 predator–prey, and when *T. urticae* population were less than 70 active mites per trifoliate, regardless of calendar date, *N. californicus* was able to maintain populations of two-spotted spider mite below damaging levels throughout a growing season (using the recommended dosage of 1–2 *N. californicus* mites per square meters). Fraulo and Liburd (2007) considered an ETL of 70–80 active mites per leaf, while Wyman et al. (1979) determined an ETL of 50 active mites per leaflet for short-day strawberry plants (Tufts), and Oatman et al. (1981, 1982) showed that 90–100 mites per leaflet had no significant effect on either fruit yield or strawberry size. However, Walsh et al. (1998) indicated detectable yield reductions on day-neutral cultivars (Selva) at population densities higher than one *T. urticae*/leaflet. Zalom (2002) pointed out that the established ETL for the first 4 months following autumn transplant is 5 mites per mid-tier leaflet, while summer transplants have an ETL of 10 mites per mid-tier leaflet. Plants are less sensitive to mite feeding once harvest begins, and the ETL increases to 15–20 mites per mid-tier leaflet. Because the ETL of this pest has not been determined in Argentina, we decided to use one of 50 active mites per leaflet (Wyman et al. 1979). Our choice was based on reducing pest densities so as not to adversely affect the production, using few chemical applications in order to promote the persistence of the predator.

Although several pesticides targeted at *T. urticae* have different side effects on *N. californicus* (Bittencourt Monteiro 2001, Sato et al. 2002, Castagnoli et al. 2005), Liburd et al. (2007) have reported that Acramite® (binfenazate) had low toxicity towards predatory mites, and was recommended for use in combination with the predatory mites for the control of *T. urticae* on strawberries (Rhodes and Liburd 2006). Similarly, Cloyd et al. (2006) and Liburd et al. (2007) found that bifenazate was not toxic to *N. californicus*. Gentz et al. (2010) recommend that abamectin should be carefully considered, particularly if conservation biological control is a desired component of a pest management programme. Nevertheless, Argentinian growers use it instead of Acramite®, owing to its lower price.

The management plan was effective and required considerably less time (25% less) than the time necessary to spray acaricide in the same area (one hour, including preparation of the chemical solutions and their application). These characteristics make the management plan feasible and useful for growers. Further, it meets both the legislation governing agrochemical use in Argentina (SENASA, 1999, 2002) and the demands of foreign markets.

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