International Journal of Agricultural Policy and Research Vol.2 (4), pp. 141-153, April 2014
Available online at http://www.journalissues.org/ijapr/

ISSN 2350-1561

Original Research Paper

Species and population dynamics of thrips occurring inside and outside greenhouses cultivated with roses in southern France

Accepted 14 March, 2014

Jeannine Pizzol[1]*, Doumar Nammour[1], Jean Michel Rabasse[1], Pia Parolin[1], Nicolas Desneux [1], Christine Poncet[1] and Philippe Reynaud[2]

[1] INRA, 400 route des Chappes, UMR1355-ISA, 06903 Sophia-Antipolis, France.
[2] ANSES, Laboratoire de la Santé des Végétaux, CBGP campus international de Baillarguet CS 30016 FR-34988 Montferrier-sur-Lez Cedex, France.

*Corresponding Author
Email: jeannine.pizzol@gmail.com
Tel.: +33 492386662,
Fax: +33 493653318

Thrips are major pests on rose crops. Monitoring and dispersal of thrips populations is of significance for the development of effective integrated pest management programs. This study was conducted to survey thrips species and their population densities occurring inside and outside rose greenhouse from year 2006-2009 in France. Among 1,850 samples collected outside, 11,617 individuals belonged to 53 species. Among 316 samples collected inside the greenhouse 2,706 individuals belonged to 7 species. The predominant species were *Thrips tabaci* (Thripidae) and *Frankliniella occidentalis* (Thripidae). Rose crops were infested mainly in spring and at the end of autumn. In this study, *Thrips australis* and *Scirtothrips inermis* were identified for the first time in France. Increasing thrips populations inside the greenhouse were related to the peak of thrips abundances outside in the spring, at time of replacement of muslin cloth used to cover the entrance of greenhouse. In autumn, no correlation was observed between pest populations inside and outside the greenhouse, where individuals of thrips present in the greenhouse continued reproduction during this period. With our data, we hope to contribute to the gain of knowledge about thrips population dynamics inside and outside greenhouses in Southern Europe.

Key words: Integrated pest management, thrips, population dynamics, greenhouse, *Thrips tabaci, Frankliniella occidentalis*

INTRODUCTION

There are nearly 10,000 thrips (Thysanoptera) species worldwide (Mound, 2002), 1% of which are considered harmful for crops. In France, 350 species have been reported, 20 species of them are actually a threat to agro-ecosystems (Reynaud P., unpublished data). Thrips are serious pests for rose crops, traditionally grown under greenhouse conditions in Southeastern France. Most harmful thrips species in greenhouses belong to the genera *Frankliniella* with 230 species reported, in particular *F. occidentalis* (Pergande) (Mound, 2012), and *Thrips*, with *T. tabaci* (Lindeman) as main pest species (Funderburk, 2002; Mound, 2012). Both these genera are worldwide in distribution (CABI/EPPO, 1969, 1999). They can survive throughout the year under greenhouse conditions due to favourite temperature and humidity (Loomans,2003). Greenhouses provide such environments and therefore can serve as reservoirs that sustain populations during the winter season (McDonald et al., 1997).

Thrips are also major invasive insects (Morse and Hoddle, 2006) and their dispersal is enhanced by human activity such as long-distance transport of plants and their products. Thrips cause considerable damage to commercial flower crops, by feeding or occasionally by transmitting some plant pathogens (Brodsgaard, 2004; Jones, 2005). To avoid damaged induced by thrips, insecticides are usually applied extensively. Such approach is associated with some disadvantages such as development of insect resistance, health cost to human and adverse effect on non-target organisms. This causes problems because of resistance of the pests (Bielza et al., 2007; Desneux et al., 2007; Biondi et

Figure 1: Study site with rose greenhouses at the INRA research center in Sophia-Antipolis, France (Lat.: 43° 36'45" N,Long.: 7° 04'40" E, Altitude: 100m)

al., 2012). *Frankliniella occidentalis* (Pergande) is established on several ornamental plants, especially Chrysanthemum and Saintpaulia, in several regions of France since 1986 (Bournier and Bournier, 1987). And since then, various vegetable crops and ornamental plants in greenhouses are subjected to attack by this pest all over France.

To develop effective pest management strategies towards this pest, accurate information about the occurrence time of thrips inside and outside the greenhouses, population dynamic, host range and distribution are needed. Therefore, this study was conducted (i) to identify the thrips species attacking the plants surrounding the greenhouses as well as (ii) to understand the population dynamics of these pests on rose crops grown under greenhouse conditions and to ascertain the origin of the populations of thrips migrating to the greenhouse. Therefore, we monitored the species present outside and inside the greenhouse in weekly samplings for three years in a study site in Southeastern France, a region which to date produces an important number of roses.

MATERIAL AND METHODS

Survey

Thrips were collected from different plants growing outside and inside the rose greenhouses at the Institute National de la Recherche Agronomique (INRA) research center in Sophia-Antipolis, France (Figure 1).

Mediterranean climate conditions are prevailing in the studying area, which are characterized by hot, dry summers and short temperate winters. Data was collected from April 2006 until April 2009, with a few exceptions due to renewal of the greenhouse and weather conditions (i.e., Nov. 2007-August 2008, and 36th and 40th week of the study, respectively).

Thrips were collected using the tapping flower method, i.e., tapping ornamental foliage plants and weeds onto a white sheet of paper (Pizzol et al., 2010). Then, by using a brush, only adults were selected and placed in 2 ml 'Eppendorf' tubes containing 10% alcohol in order to be identified. Larvae were not sampled because even if some recently dichotomous keys were available, many thrips in immature stages could not be identified with certainty to the species level using morphological methods (Mehle and Trdan, 2012). Measurements of temperature and relative air humidity were performed using an Aria hygrometry sonde (ref. SDE-HYGRO-4) and Aria temperature sonde (ref. SDTEOA45, SDTS 0/60) outside and inside the greenhouse. Insecticides were applied twice inside the greenhouse, but not outside. In the third year (after November 2007) pesticides were not applied at all. Dedevap® (active ingredient: dichlorvos) was used against aphids in week 24 of 2006 and Fuoro® (active ingredient: lufenuron) in weeks 37 and 42 in the year 2006 against thrips.

Sampling outside the greenhouses

In order to have a precise overview of both ligneous and herbaceous flowering plants in a given week, samples were collected at random outdoors in an area up to 300 m around the greenhouse where no chemical treatments were made. About a dozen plants were sampled each week and the choice of plants was linked to the presence of thrips. Each sample (tube) was a host plant bearing one or more thrips species. Thereafter, plants were systematically recorded and identified (Pizzol et al. in prep.). 108 plant species representing 42 families were recorded.

Sampling in the greenhouse

The samples were taken from roses cropped in integrated pest management (IPM). The IPM rose greenhouse in Sophia-Antipolis (INRA, France) measured 576 m^2 with 5.6 rose plants per m^2 and consisted of three compartments (Poncet et al., 2010). This greenhouse was the Multiclair 9600 type, i.e., covered with a Triclair-Inc 45, 200μ film. It was oriented north-south and equipped with "anti-Bemisia" type butterfly mesh nets (Ref: 3306: mesh of 400 × 770 microns). Each compartment has five double rows of roses and each row three cultivars (cv. Magnum ®, cv. Milva ®, cv. Suela ®). Roses were planted on May 6, 2003 and were grown above ground on rock wool. This culture was renewed in autumn of 2007. A new crop was planted in May 2008 (cv. Dark Milva ®) and the same conditions were used. The thrips were sampled weekly by tapping 150 roses, mainly the flower and / or bud (50 of each cultivar until the autumn of 2007 and 150 roses of Dark Milva ® from May 2008 to April 2009). Rose blooms were lightly tapped three times over a white sheet of paper according to the method described by Pizzol et al. (2010).

Thrips identification

The packaged samples were identified in Montpellier by the Entomology unit of the National Laboratory of Plant Protection (LNPV, now named LSV). Firstly, thrips were observed using a stereomicroscope (LEICA MZ12 with a magnification of 8 to 100 ×), then they were placed in lactic acid to be examined under an optical microscope (LEICA DMLB2, with a magnifying range from 50 to 630 ×). When necessary, thrips were slide-mounted in Canada balsam. Aeolothripidae, Melanthripidae and Thripidae were identified using the key presented by zur Strassen (2003). Phlaeothripidae were identified according to Priesner (1964) and Schliephake and Klimt (1979). Voucher specimens were deposited in the Thysanoptera reference collection of Anses-LSV (Laboratoire de la Santé des Végétaux, CBGP Baillarguet International Campus, Montferrier-sur-Lez Cedex, France).

Statistical analyses

All data were classified using eight variables: year, week, location (greenhouse, outdoor), host plant, sampling date, family, genus, species of thrips as well as a quantitative variable i.e., the number of thrips. Simple linear regression (Statview, SAS Institute Inc., Cary, NC, USA) was used to test the relationship between outdoor thrips populations and thrips populations on crops in the greenhouse.

RESULTS

Thrips outside the greenhouses

The number of thrips collected between April 2006 and April 2009 amounted to 11,617 specimens on the 1,850 samples. Fifty-three species of thrips were recorded outside over those 3 years (Table 1), where both suborders (Terebrantia and Tubulifera) were present. The majority of thrips collected on plants belonged to the suborder Terebrantia and more specifically to the *Thrips* genus and Thripidae family (90% of the total). Melanthripidae was recently recognized as a separate family from the Aeolothripidae. In our study, *Melanthrips* (about 6%) are well represented. They are probably phytophagous, feeding and breeding within flowers. Aeolothripidae are facultative predators of other small arthropods, they represent two genera and 3.35% of the total. The other sub-order (Tubulifera) includes a single family, the Phlaeothripidae and represents 0.58% of the total (Table 1).

The main species found was *T. tabaci* representing 38.23% of the total count, followed by *Thrips major* (Bagnall) 13.99%, *Melanthrips fuscus* (Sulzer) 5.78%, *Tenothrips frici* (Uzel) 5.12%, *Thrips minutissimus* Linnaeus 4.65%, *Thrips angusticeps* Uzel 4.52%, *Thrips flavus* Schrank 4.35%. *Frankliniella occidentalis* represents 3.17% of thrips sampled (Table 1).

During the course of this study, two other species were found, *Microcephalothrips abdominalis* (Crawford) previously recorded in France (Pizzol et al., 2012), and *Thrips hawaiiensis* (Morgan), which had previously been recorded in Europe by Reynaud et al (2008). *Thrips*

Table 1. List of thrips species present outside from April 2006 to April 2009 in Sophia-Antipolis (France): % compared to the total number of thrips individuals collected outside (*: first record in France; **: first record in France by Pizzol at al., 2012; ***: first record in Europe by Reynaud et al., 2008).

TEREBRANTIA	% comparison
Aeolothripidae	
Aeolothrips collaris Priesner	0.34%
Aeolothrips ericae Bagnall	0.35%
Aeolothrips gloriosus Bagnall	0.33%
Aeolothrips intermedius Bagnall	0.09%
Aeolothrips melaleucus (Haliday)	0.03%
Aeolothrips tenuicornis Bagnall	2.07%
Rhipidothrips gratiosus Uzel	0.15%
Melanthripidae	
Melanthrips fuscus (Sulzer)	5.78%
Melanthrips rivnayi Priesner	0.04%
Thripidae	
Anaphothrips obscurus (Muller)	0.01%
Aptinothrips rufus (Haliday)	0.20%
Bregmatothrips dimorphus (Priesner)	0.01%
Dendrothrips phyllireae (Bagnall)	0.08%
Frankliniella occidentalis (Pergande)	3.17%
Heliothrips haemorrhoidalis (Bouche)	0.13%
Limothrips cerealium (Haliday)	0.25%
*Microcephalothrips abdominalis*** (Crawford)	0.01%
Mycterothrips annulicornis (Uzel)	0.03%
Odontothrips dorycnii Priesner	0.16%
Odontothrips karnyi Priesner	0.03%
Odontothrips loti (Haliday)	0.01%
Oxythrips ajugae Uzel	0.14%
Oxythrips nobilis Bagnall	0.01%
Pezothrips kellyanus (Bagnall)	1.97%
Rubiothrips vitalbae (Bagnall)	0.01%
*Scirtothrips inermis** Priesner	2.02%
Scolothrips latipennis Priesner	0.01%
Stenothrips graminum Uzel	0.85%
Taeniothrips inconsequens (Uzel)	0.02%
Tenothrips croceicollis (Priesner)	3.40%
Tenothrips discolor (Karny)	0.04%
Tenothrips frici (Uzel)	5.12%
Tenothrips ononidis (Bournier)	0.02%
Thrips alni Uzel	0.01%
Thrips angusticeps Uzel	4.52%
*Thrips australis** (Bagnall)	0.58%
Thrips brevicornis Priesner	0.20%
Thrips flavus Schrank	4.35%
Thrips fuscipennis Haliday	0.02%
*Thrips hawaiiensis**** (Morgan)	3.17%
Thrips major Uzel	13.99%
Thrips meridionalis (Priesner)	1.36%
Thrips minutissimus Linnaeus	4.65%
Thrips nigropilosus Uzel	0.14%
Thrips pelikani Schliephake	0.67%
Thrips physapus Linnaeus	0.33%
Thrips pillichi Priesner	0.02%
Thrips tabaci Lindeman	38.23%
Thrips trehernei Priesner	0.02%
Thrips verbasci (Priesner)	0.01%

Table 1 cont.

TUBULIFERA	
Phlaeothripidae	
Haplothrips andresi Priesner	0.47%
Haplothrips subtilissimus (Haliday)	0.11%

Table 2. List of thrips species present inside the rose greenhouse (compartments 2-3-4) from April 2006 to April 2009 in Sophia-Antipolis (France): % compared to the total number of thrips individuals collected inside.

TEREBRANTIA	
Thripidae	% comparison
Frankliniella occidentalis	**80.04%**
Scirtothrips inermis	0.04%
Thrips flavus	0.22%
Thrips hawaiiensis	0.04%
Thrips major	0.22%
Thrips minutissimus	0.08%
Thrips tabaci	19.36%
Total Thrips	**19.92%**

hawaiiensis represented 3.17% of thrips sampled.

Thrips inside the IPM rose greenhouse

Only seven of all species found outside were recorded also inside the rose greenhouse (Table 2): *Frankliniella occidentalis*, *Thrips tabaci*, *T. hawaiiensis*, *T. major*, *T. flavus*, *T. minutissimus* and *Scirtothrips inermis* Priesner from 2,706 specimens, 316 samples. Two species, *F. occidentalis* and *T. tabaci*, represented 80% and 19% of thrips recorded from 2006 to 2009. Five other species were found occasionally inside this rose greenhouse (< 1%) (Table 2).

Interannual variations of the dominance of thrips species became evident. In 2006, *F. occidentalis* represented 57% and *T. tabaci* 41.7% (770 thrips); in 2007, *F. occidentalis* represented 81.8% and *T. tabaci* 17.5% (798 thrips); in 2008, *F. occidentalis* represented 93.3% and *T. tabaci* 6.6% (955 thrips). In 2009, this percentage reached 100% (183 thrips) but was not representative of the year because sampling was discontinued in April.

Seasonal variations and correlations between the populations outside and inside

2006 season

There was a first peak of thrips outside in spring (weeks 21 to 24, maximum week 22) (Figure 2A-B) and populations remained high until the second peak in autumn (weeks 39 to 46, maximum week 40) which was greater than the one in spring. During that period, thrips populations remained relatively high until the end of the year. *Frankliniella*

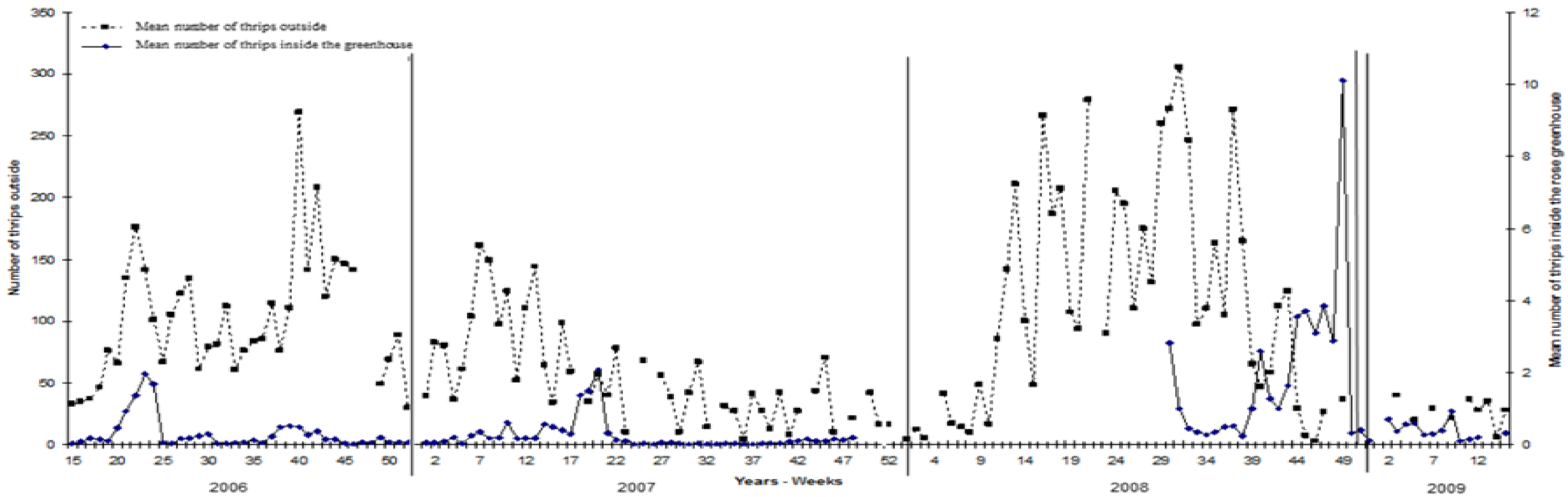

Figure 2A: Thrips population outside and inside (total number of sample) of the IPM rose greenhouse from April 2006 to April 2009

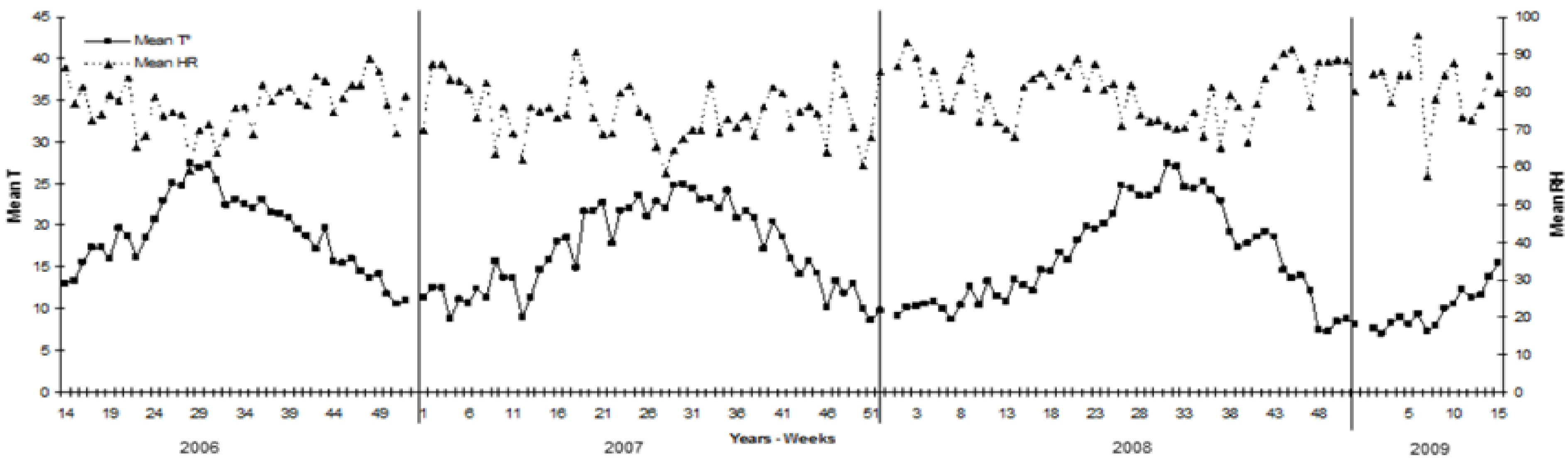

Figure 2B: Mean temperature (in °C) and relative humidity (RH), outside in Sophia Antipolis site, from April 2006 to April 2009.

occidentalis represented only 1.96% of thrips sampled, *T. tabaci*, 43.2% and the other species represented 54.9% (Figure 3 A-B-C).

Inside the rose greenhouse, the first significant infestation was observed in spring 2006 (weeks 22 to 24); there were more than 75 individuals for 150 roses sampled (higher than the threshold for beneficial releases i.e., 0.5 thrips / rose). In this first infestation, there were approximately 20% *F. occidentalis*, 79.39% *T. tabaci* and 0.61% other species (Figure 3 A-B-C). There was also a great increase in *T. tabaci* and *F. occidentalis* in week 19 outside, except for one week in spring while the nets were being replaced. The second infestation, in early autumn 2006, appeared two weeks prior to that inside the greenhouse and was much smaller, i.e., more than 30 individuals on the 150 roses sampled. These populations were curbed in the same period by using insecticides. This second infestation was composed of more than 90% *F. occidentalis*. Outdoors, *T. tabaci* was present continuously and exclusively until December and *F. occidentalis* appeared only occasionally between weeks 24 to 37; thereafter, between weeks 41 and 46. However, *F. occidentalis* was present in the greenhouse at the same time and continuously from week 37.

The presence of the thrips populations outside and inside the greenhouse was significantly correlated for the period between weeks 15 and 23 in 2006 (F = 24.64, d.f. = 7, P = 0.002) or when the correlation was made throughout the year 2006 (from weeks 15 to 52) (F = 0.115, d.f. = 34, P = 0.043). There was no significant correlation when we considered weeks 24 to 52 in 2006. The correlation for the weeks 15 – 23 matched the one when the nets were replaced. Thrips entry had been massive at that period, i.e., *F. occidentalis* represented only 22.61% whereas there was a majority of *T. tabaci* in the greenhouse (75.76%). At that same time, *T. tabaci* was also present outside in great numbers (a total of 50.70%).

2007 season

Thrips populations outside were higher in winter and early spring than in the rest of the year (Figure 2). Clearing weeds around the IPM greenhouse most likely accounted for a lower count in the thrips populations outside. *Frankliniella occidentalis* represented only 0.94% of thrips sampled, *T. tabaci* 23.4% and other species represented 75.66% for the whole year (Figure 3 D-E-F). Considering how heavy the infestation was until week 13, *T. tabaci* represented 0.24% of the total population, *F. occidentalis* was not present and other species represented 99.76% of the total. *Frankliniella occidentalis* appeared in week16 (Figure 3 D).

Inside the greenhouse (compartments 2-3-4), thrips populations began to rise between week 7 and week 22 the peak weeks being 18-19-20 (Figure 3D). The spring infestation between weeks 18 and 20 was almost exclusively composed of *F. occidentalis* (90%) (Figure 3 D-E-F) and there was a peak in weeks 18, 19 exceeding 140 individuals per 150 roses sampled. At that time, the treatments with Conserve® (active ingredient: spinosad) (week 16) and Apollo (active ingredient : clofentézine) Vertimec (active ingredient : abamectine) (week 23) decreased thrips populations. The second infestation in autumn (weeks 42 to 48) was much smaller than the first one i.e., number of individuals was lower than 20 thrips per 150 roses sampled and almost entirely composed of *T. tabaci* (more than 70%) (Figure 3 D-E). This species was also present outside the greenhouse (49.68% of the total) (Figure 3 E). The presence of *T. tabaci* in the greenhouse might be partly due to thrips from outside and a following multiplication of thrips inside the greenhouse. However, in 2007 overall for thrips species, (weeks 1 to 48), there was no correlation between the populations outside and inside the greenhouse (F = 0.61; d.f. = 40, P = 0.438).

2008 and early 2009 season

There was a rise in thrips populations outside from week 13 onwards and the population level remained high until week 43 (Figure 2). Thereafter, populations remained relatively low even until the end of our study. In 2008, *F. ocidentalis* represented 4.85% of the number of thrips collected, *T. tabaci* 40.42% and the other species accounted for 54.74%. Data from 2008 and 2009 are less complete as the greenhouse had to be maintained, and therefore they are not shown in Figure 3.

Population dynamics of further species in the greenhouse

Other species (*Thrips hawaiiensis*, *T. flavus*, *T. major*, *T. minutissimus* and *Scirtothrips inermis*) were occasionally recorded in the greenhouse in very low numbers i.e., not more than six individuals per species (Figure 3 C-F). In some cases, these other species entered the greenhouse in small numbers. *Thrips hawaiiensis*, mainly present in late summer and autumn, was collected in a greenhouse in autumn 2006. *Thrips major*, present outdoors in spring, autumn 2006 and winter 2007, was found in those same periods in the greenhouse. *Thrips flavus* sampled outdoors in spring and late autumn - early winter 2006 and 2007 was found in the greenhouse in spring. *Thrips minutissimus* found outside in spring 2006 was also found inside the greenhouse (2 individuals). In summer 2008 (week 33), another species, *Scirtothrips inermis*, was found inside the IPM greenhouse on the new rose crop (Dark Milva®).

DISCUSSION

Diversity of species

Thrips diversity outside the greenhouse was high

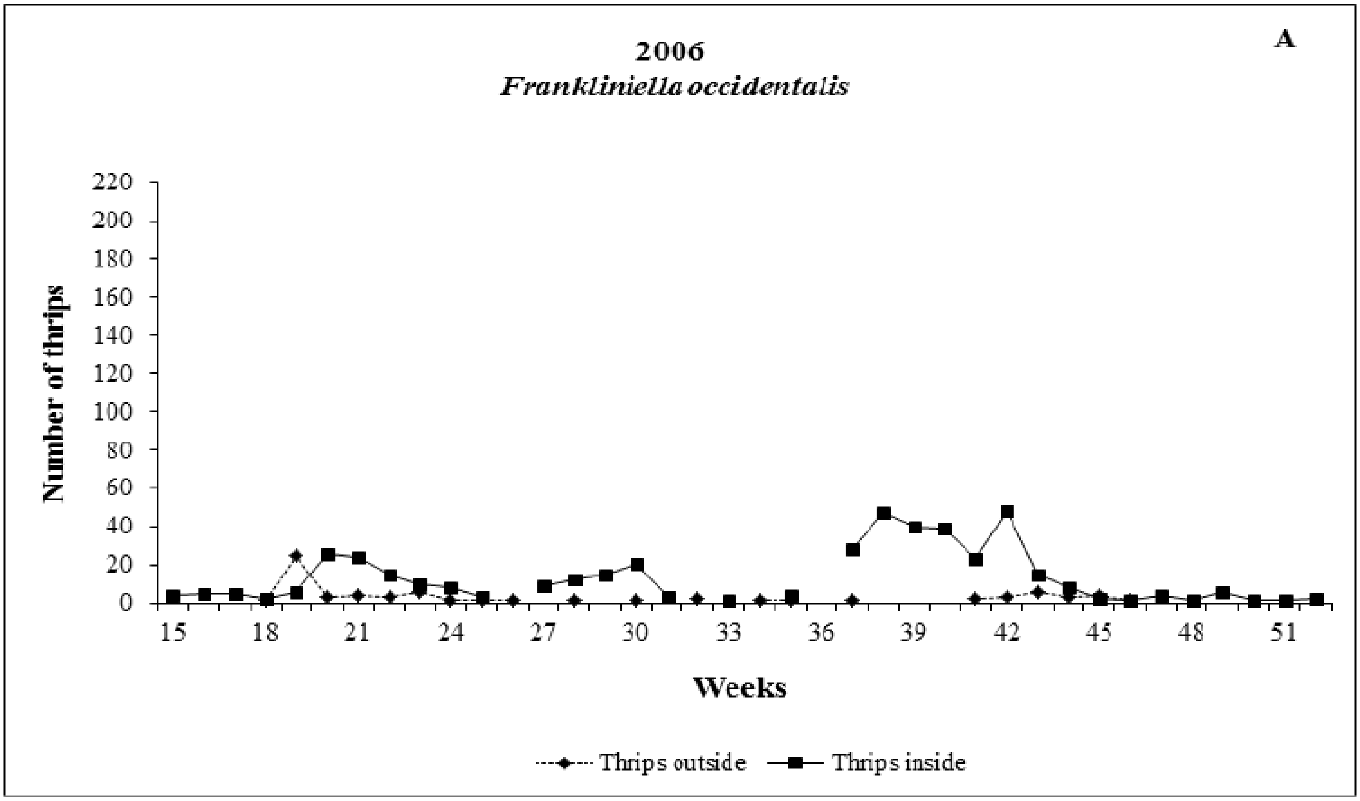

Figure 3A: Dynamics of *Frankliniella occidentalis* population outside and inside the IPM greenhouse in 2006

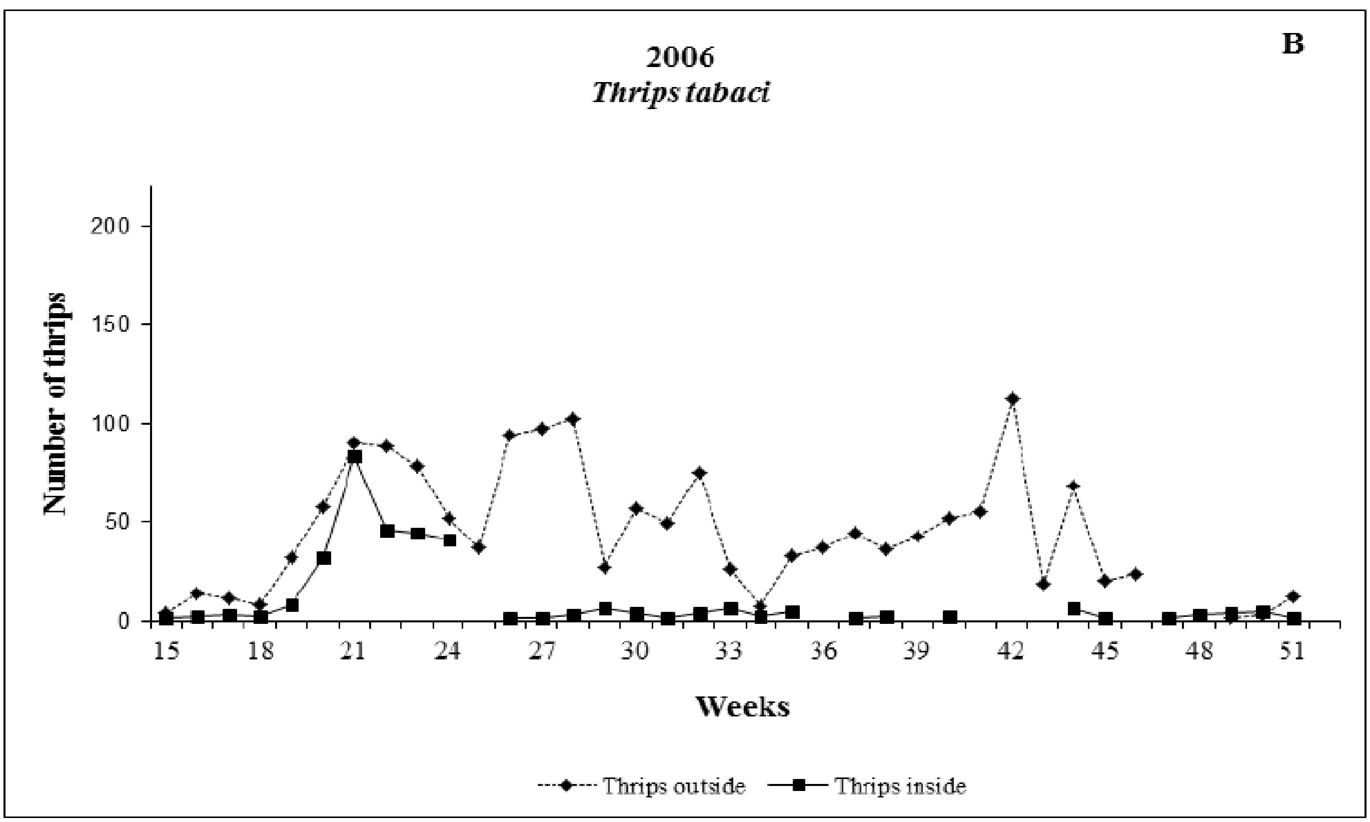

Figure 3B: Dynamics of *Thrips tabaci* population outside and inside the IPM greenhouse in 2006

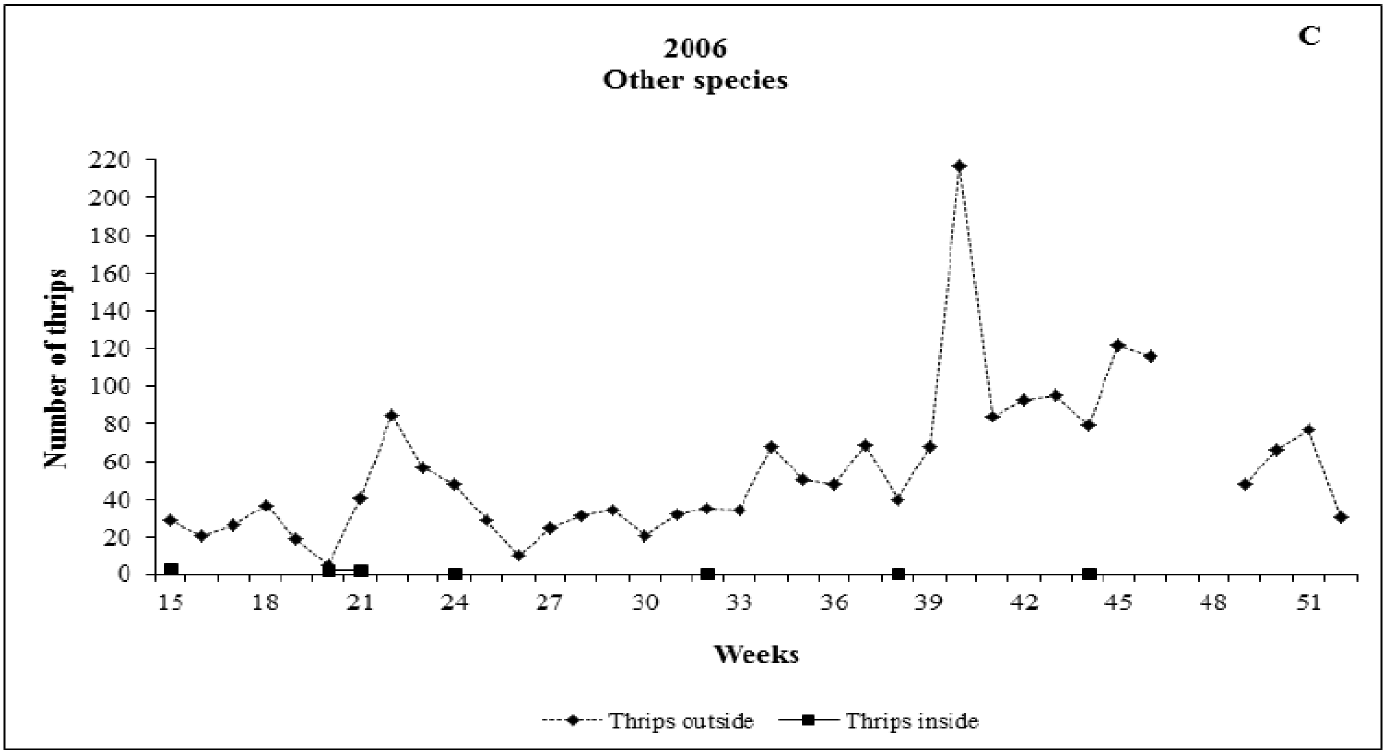

Figure 3C: Population dynamics of other thrips species outside and inside the IPM greenhouse in 2006

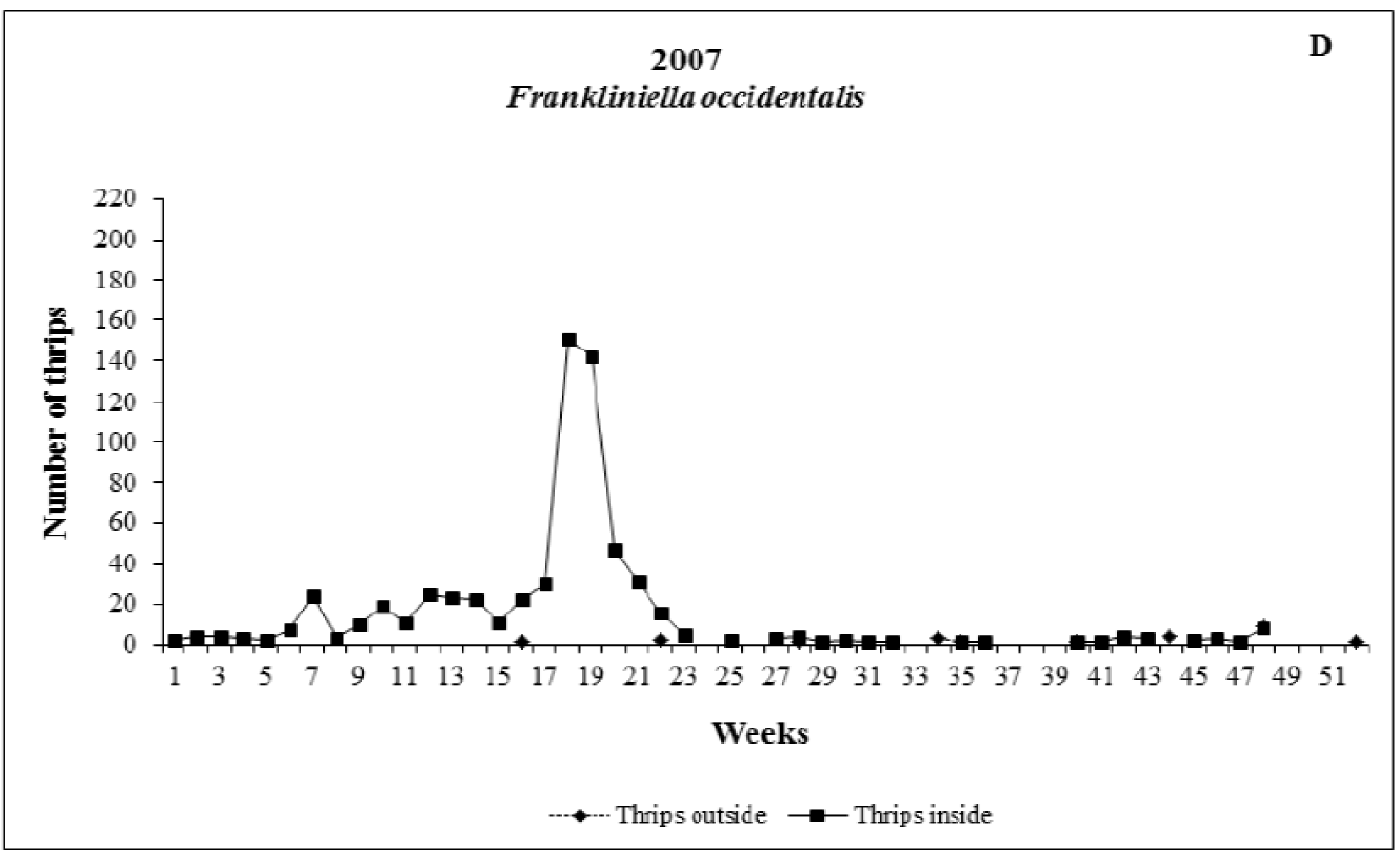

Figure 3D: Dynamics of *Frankliniella occidentalis* population outside and inside the IPM greenhouse in 2007

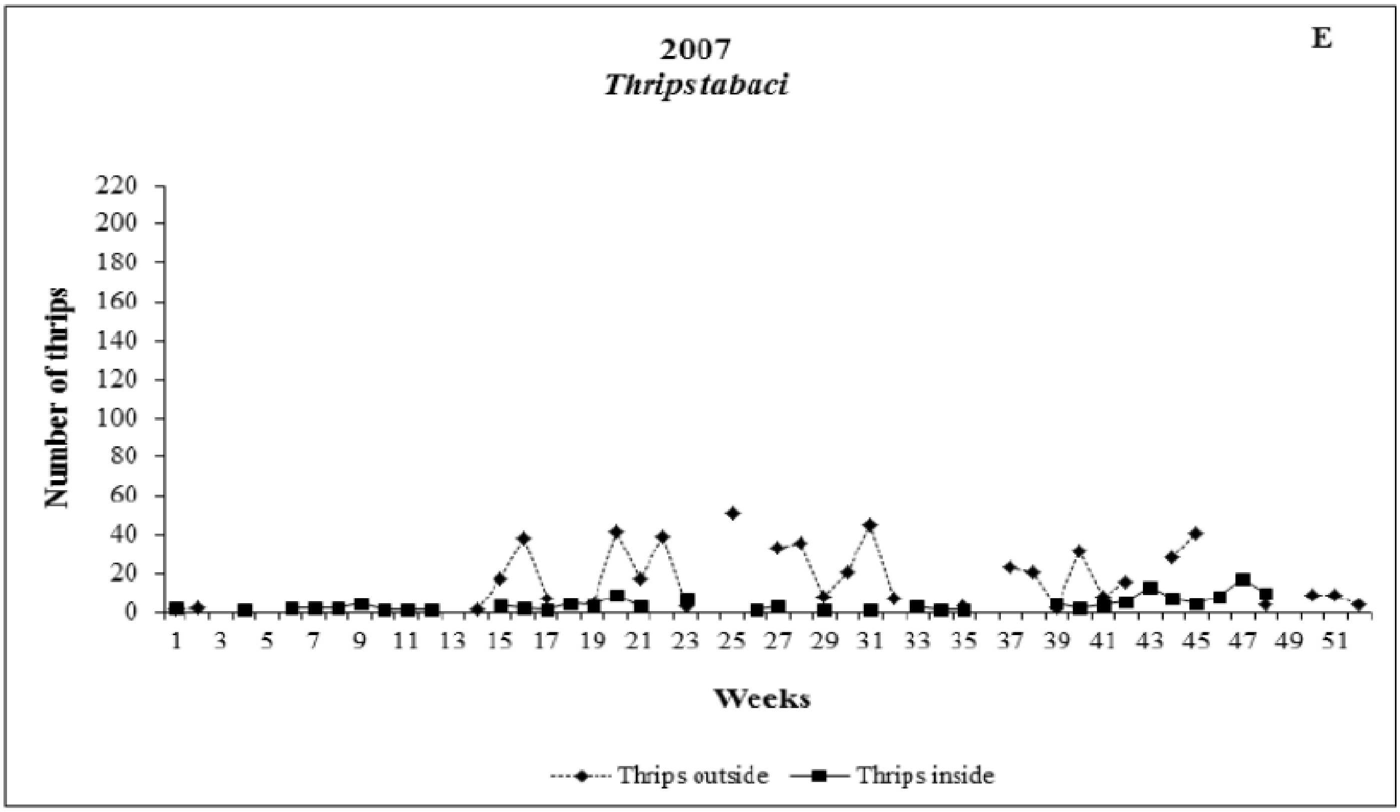

Figure 3E: Dynamics of *Thrips tabaci* population outside and inside the IPM greenhouse in 2007

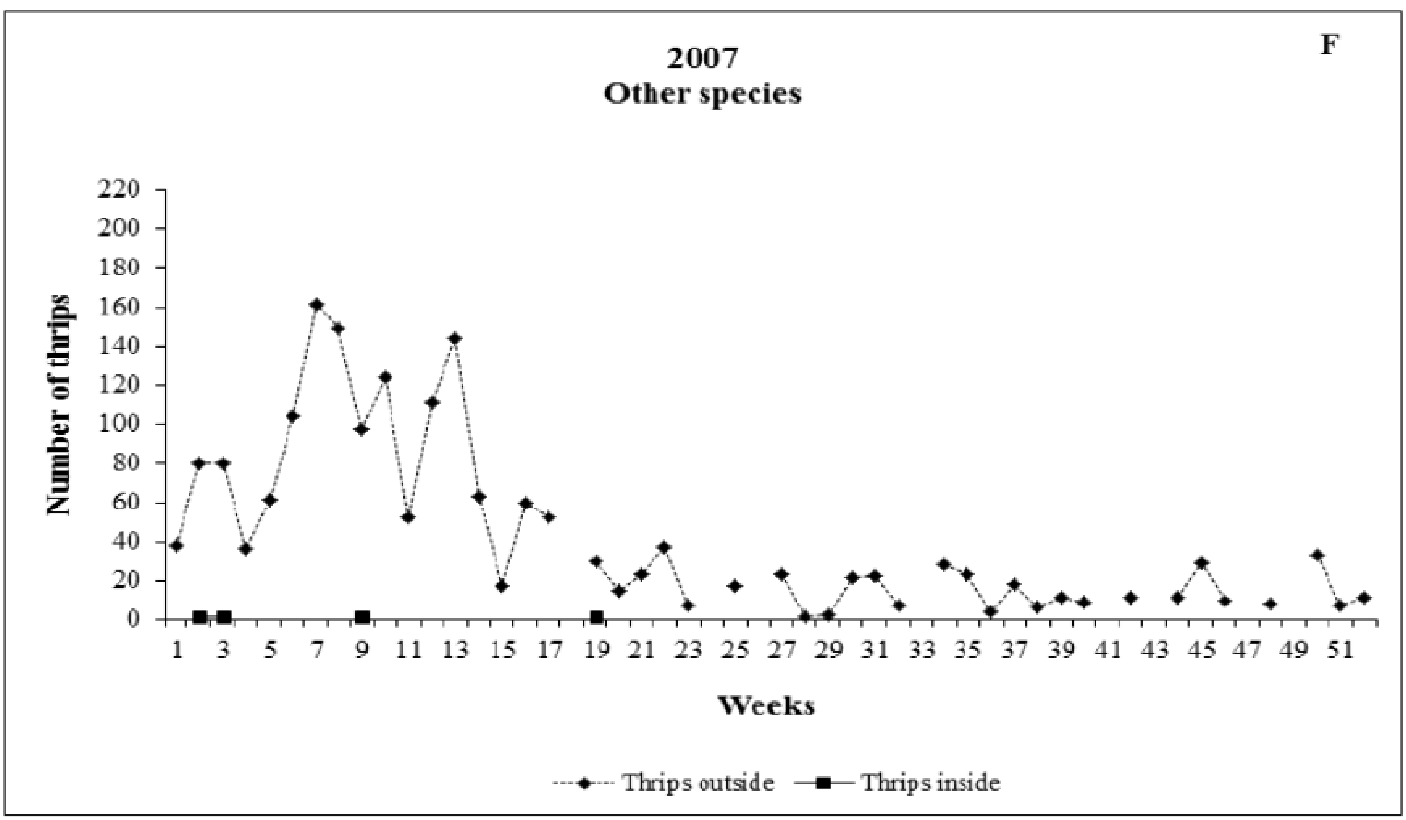

Figure 3F: Population dynamics of other thrips species outside and inside the IPM greenhouse in 2007 throughout the three years, with two suborders (Terebrantia and Tubulifera) and four thrips families present: Aeolothripidae, Melanthripidae, Thripidae and Phlaeothripidae. Two of its genera, *Frankliniella* and *Thrips* greatly impact worldwide agriculture and economics. These genera can cause serious direct damage by feeding on many crops (flowers and leaves; Trdan et al., 2008) and indirect harm by transmitting tospoviruses (Mound, 1997; Jenser et al., 2003). *Thrips tabaci* was the most widespread species found outside on the site of Sophia-Antipolis.

New species reports

Two species were recorded for the first time in France: *Thrips australis* (Bagnall) and *Scirtothrips inermis* Priesner.

Thrips australis

Thrips australis is a large, distinctively bicoloured Australian species which has spread to warmer countries worldwide (Palmer, 1992). Its actual world distribution is given by Minaei (2012) and includes Mediterranean countries such as Spain, Italy, Portugal, Greece, Tunisia, Egypt, Israel, Cyprus, Canary Islands. In Australia, this species feeds mainly on *Eucalyptus* flowers but there are numerous published records where it has been collected on various plants and considered a polyphagous species. *Thrips australis* has also been frequently recorded in quarantine interceptions in northern countries (Collins, 2010). Prior to this study, this thrips had not been recorded in France.

Scirtothrips inermis

The genus *scirtothrips* includes more than 100 species of small leaf-feeder thrips, several of which are damaging crop plants. Even though *Scirtothrips inermis* was reported in the Canary Islands, there is uncertainty as to where it originates from (Hoddle and Mound, 2003). It has however been recorded over a wide area around there. Currently, it is distributed in Mediterranean countries but it has not so far been recorded in the mainland of France. Conti and Vesmanis (2001) collected this species in Corsica in 1999. *Scirtothrips inermis* was found on *Ilex*, *Myrtus*, *Rosa*, *Tamarix* (zur Strassen, 2003) and it is a secondary pest on *Citrus* leaves and fruits (Lacasa et al., 1996).

In total during the study period three species, *Scirtothrips inermis*, *Thrips australis* and *Microcephalothrips abdominalis*, (Pizzol et al., 2012) were found for the first time in France (or France mainland for *S. inermis*) and *Thrips hawaiiensis* was encountered for the first time in Europe (Reynaud et al., 2008). They all belong to the large Thripidae family.

Major guilds outside vs. inside

Over half of all species of thrips feed on non-woody parts of plants (crop pests are included in this group) and the rest of the Thysanoptera consists mainly of fungus-feeding species (largely confined to tubuliferan thrips) and a few specialist predators (Kirk, 1997). Trapping techniques were deliberately not adapted or designed to capture fungus-feeding thrips that live on dead wood or leaf litter. This explains the fact that the Tubulifera suborder represents only 0.6% of the thrips collected in Sophia-Antipolis. These thrips have no direct impact on the rose production, except perhaps some species of the *Haplothrips* genus present in this study, which feeds on plants (Mound, 1997). The Aeolothripidae, 3.38% of thrips recorded in Sophia-Antipolis, encompass predators such as *Aeolothrips*. This genus was represented by six species in our study, including *Aeolothrips intermedius* Bagnall and *A. gloriosus* Bagnall. According to Bournier et al. (1978) the larvae of this species are excellent predators of other Thysanoptera, mites, whiteflies and psyllids. *Melanthrips fuscus*, is a frequent species in Europe, probably phytophagous, even if there are few studies on Melanthripidae biology and life history.

Correlations of thrips between outside and inside in the greenhouse

In our study, we document the long-term development of thrips populations outside and inside an IPM rose greenhouse under real conditions, such as are found among the local producers, including cuttings of the surrounding vegetation and occasional use of pesticides. We could document that thrips populations inside the greenhouse were significantly correlated with the appearance and peak of species and individuals outside in spring for some weeks. Immigration was thus the principal cause for the presence of high number of thrips inside the greenhouse. Species inside were all present outside. It would seem, in fact, that greenhouse infestation came mainly from the outside in 2006 when the protecting nets were replaced (Figure 3 A-B). In autumn, however, a second peak of individuals found in the greenhouse was not correlated with the outside population, indicating that the reproduction of already established individuals inside the greenhouse was responsible for the high number of thrips found inside the greenhouse. The populations inside the greenhouse after the net replacement seemed to be more a result of a thrips multiplication inside the greenhouse triggered by favourable climatic conditions in the protected environment (Korner and Jakobsen, 2006).

Intra- and interannual variations

The dynamics of thrips populations varied from year to year, mainly outside, but also in the greenhouse. Therefore it is usually difficult to anticipate and therefore hinders the control of thrips populations which appear inside the rose greenhouses. Correlations with temperature and relative air humidity could not be detected, although the extremes play a role for the survival of the thrips, reason why in autumn the greenhouses offer a more favourable environment for their replication than the open spaces.

For three years, *F. occidentalis* was the dominant species in the rose crops, compared to *T. tabaci.* However, the relative dominance of *F. occidentalis* differed between years, with 57% in 2006, 81.8% in 2007, 93.3% in 2008 and 100% in 2009 (January - April 2009) inside the rose greenhouse. *Frankliniella occidentalis* tended to progressively replace *T. tabaci*, and observation made before in other studies as well (Carvalho et al., 2005). *Frankliniella occidentalis* would remain inside the greenhouse. However, in 1995 and 1996, in Germany Sauer (1997) found on this same rose crop that *T. tabaci* predominated (although on a decreasing trend from 1995 to 1996 i.e., respectively 56.2% to 44.5%), while *F. occidentalis* increased respectively to 15.6 and 29.8%. Another species, *T. fuscipennis* Haliday*,* was also present in the German greenhouses with 12.2% in 1995 and 15.1% in 1996.

In 2008, the evolution of the thrips population was clearly distinct from the one in 2006. On the new rose crop (Dark Milva®), *F. occidentalis* was dominant whereas other thrips species disappeared, e.g., *T. tabaci* which disappeared gradually. At the end of our study, we had 100% *F. occidentalis*. Favourable conditions and competition between species may partly explain this phenomenon, but the rose variety which is particularly attractive to *F. occidentalis* may also be taken into consideration. It has facilitated the installation and maintenance of *F. occidentalis* to the disadvantage of the other species.

Overwintering populations inside the greenhouse

One goal of our study was to understand the origin of the populations of thrips in the greenhouse, whether the pests immigrated from outside or multiplied within the greenhouses. We found that both occur, with immigration being the primary reason for thrips presence in spring, and multiplication inside the greenhouse in autumn.

According to Loomans (2003), *F. occidentalis* can successfully reproduce outdoors in northern and central Europe during hot summers, but would not be able to survive winter conditions as it cannot withstand low temperatures. Outside the greenhouses on site, *F. occidentalis* was present from February to December, depending on the year and temperatures. Its relative abundance in outdoors observations was low. Two hypotheses are possible: *F. occidentalis* is in the greenhouse and can feed outside or the thrips may remain over winter if the climate is mild (Trdan, 2003; Orosz, 2009). As for *Thrips tabaci*, Mound (1997) also confirmed that he observed its populations increase when temperatures go up.

Overall, without nets, thrips infest greenhouse crops massively. With nets, a smaller number of thrips enter the greenhouse, but the majority of thrips populations resulted from a thrips multiplication inside the greenhouse. This is true for *F. occidentalis* in particular when it encounters favourable climatic conditions, it may represent more than 80% of the thrips population. However, two periods of infestation appeared until 2007, one in spring and one in autumn. The first infestation in 2006, in late spring in the greenhouse, could probably be explained by the combination of a massive entry of *T. tabaci* from outside and a smaller one of *F. occidentalis*, with development of each species when favourable conditions appeared in the greenhouse. The second infestation, in turn, is linked to the development and maintenance inside the greenhouse of *F. occidentalis*. We also observed that *T. tabaci* re-appears later in the year in the greenhouse while it is still present outside. In 2007, the spring infestation may stem from thrips left over from the previous year (2006) (*F. occidentalis* and *T. tabaci*) in the greenhouse with relatively little input from the outside. The infestation in autumn (weeks 42 - 48) is linked almost exclusively to the presence of *T. tabaci* that would have entered the greenhouse in small numbers and would be maintained there.

Conclusions

This study aimed at assessing the importance of various factors that are critical to understanding the infestations of greenhouse by thrips: (i) favourable micro-climatic conditions inside the greenhouses, (ii) net opening, (iii) the external conditions for the development of some important thrips species based on plant species outside the greenhouses which are the basis for a spring infestation of the greenhouse, and (iv) the rose varieties. We hope to contribute to the gain of knowledge about thrips population dynamics inside and outside greenhouses in Southern Europe.

ACKNOWLEDGMENTS

We thank Antonio Biondi, Marie-Madeleine Muller and Legaud Virginie for their comments on an earlier version of the manuscript, Sophie Voisin and Michel Ziegler for their technical assistance in this work, and INRA for funding support.

REFERENCES

Bielza P, Quinto V, Contreras J, Torne M, Martin A, Espinosa PJ (2007). Resistance to Spinosad in the Western Flower Thrips *Frankliniella occidentalis* (Pergande), in Greenhouses of South-Eastern Spain. Pest Manag. Sci. 63: 682-687.

Biondi A, Desneux N, Siscaro G, Zappalà L (2012). Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere. 87: 803-812.

Bournier A, Bournier JP (1987). L'introduction en France d'un nouveau ravageur: *Frankliniella occidentalis*. Phytoma. 388: 14-17.

Bournier A, Lacasa A, Pivot Y (1978). Régime alimentaire d'un thrips prédateur *Aeolothrips intermedius* (Thys.: Aeolothripidae). Biocontrol. 24: 353-361.

Brodsgaard HF (2004). Biological control of thrips on ornemental crops. In: Heinz KM, Van Driesche RG, Parrella MP (Eds) BioControl in Protected Culture, Ball Publishing, Bataia. IL pp. 253-264.

CABI / EPPO (1969). Distribution Maps of Pests. Pest: *Thrips tabaci* Lind. (Thysanopt., Thripidae) (Onion Thrips). Host Plants: Polyphagous; vector of virus deseases of tobacco, tomato, pineapple, etc. Commonealth Agricultural Bureaux. 1969.

CABI / EPPO (1999). Distribution Maps of Pests N° 538. *Frankliniella occidentalis* (Pergande) Thysanoptera: Thripidae. Host Plants: Polyphagous. CAB International. 1999.

Carvalho AR, Bueno VHP, Diniz AJF (2005). *Thrips* (Thysanoptera) in protected rose crops in Brazil. Integrates Control in Protected Crops, Temperature Climate IOBC/wprs Bull. 28: 39-42.

Collins DW (2010). Thysanoptera of Great Britain: a revised and updated checklist. Zootaxa. 2412: 21-41.

Conti B, Vesmanis A (2001). The entomofauna of Corsica, coastal Tuscany and the islands of the Tuscan Archipelago: Thysanoptera (Insecta). Frustula Entomol. 24: 125-142.

Desneux N, Decourtye A, Delpuech JM (2007). The sublethal effects of pesticides on beneficial arthropods. Ann. Rev. Entomol. 52: 81-106.

Funderburk JE (2002). Ecology of thrips. In: *Thrips and tospoviruses.* Proceedings of the 7th International Symposium on Thysanoptera. Marullo R and Mound LA (Eds.) pp. 121-128 Australian National Insect Collection, Canberra, Australia.

Hoddle MS, Mound LA (2003). The genus *Scirtothrips* in Australia (Insecta, Thysanoptera, Thripidae). Zootaxa 268: 1-40.

Jenser G, Gáborjányi R, Szénási A, Almási A, Grasselli M (2003). Significance of hibernated *Thrips tabaci* Lindeman (Thysan., Thripidae) adults in the epidemic of tomato spotted wilt virus. J. Appl. Entomol., 127, 1:7-11.

Jones DR (2005). Plant viruses transmitted by thrips. Europ. J. Plant Pathol. 113: 119-157.

Kirk WDJ (1997). Feeding. In: Lewis T, (Eds.). Thrips as crop pests, pp. 119-174. CAB International, Wallingford, UK.

Körner O, Jakobsen L (2006). A thrips pest pressure model for greenhouse climate control. Acta Hortic, 718:407-414.

Lacasa A, Llorens JM, Sanchez JA (1996). Un Scirtothrips (Thysanoptera: Thripidae) causa daños en los cítricos en España. San. Veg. Plagas. 22: 79-95.

Loomans AJM (2003). Parasitoids as Biological Control Agents of Thrips Pests. Chapter 1: Evaluation of hymenoterous parasitoids as biological control agents of thrips pest in protected crops, introduction. The Netherlands. 1-45, pp.199.

McDonald JR, Bale JS, Walters KFA (1997). Effects of sub-lethal cold stress on the Western Flower Thrips, *Frankliniella occidentalis*. Ann. Appl. Biol. 131: 189–195.

Mehle N, Trdan S (2012). Traditional and modern methods for the identification of thrips (Thysanoptera) species. J. Pest Sci. 85: 179-190.

Minaei K (2012). First report of an endemic Australian thrips, *Thrips australis* (Thysanoptera: Thripidae) on Eucalyptus in Shiraz, Iran. J. Entomol. Acarol. Res. 44: e9.

Morse MS, Hoddle MS (2006). Invasion biology of thrips. Ann. Rev. Entomol. 51: 67–89.

Mound LA (1997). Biological diversity. Thrips As Crop Pests (ed. by T.Lewis). pp. 197–215. CAB International, UK.

Mound LA (2002). Thysanoptera biodiversity in the Neotropics. Rev. Biol. Trop. 50: 477-484.

Mound LA (2012). Thysanoptera (Thrips) of the World–a checklist. http://www.ento.csiro.au/thysanoptera/worldthrips.html

Orosz S (2009). Observations on the overwintering of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) under climatic conditions of Hungary. Acta Phytopathol. Entomol. Hungar., 44: (2):267-276

Palmer JM (1992). Thrips (Thysanoptera) from Pakistan to the Pacific: a review. Bulletin of the British Museum. (Natural History), Entomol. 61: 76.

Pizzol J, Nammour D, Hervouet P, Bout A, Desneux N, Mailleret L (2010). Comparison of two methods of monitoring thrips population in a greenhouse rose crop. J. Pest Sci. 83: 191-196.

Pizzol J, Reynaud P, Desneux N, Poncet C (2012). *Microcephalothrips abdominalis* (Thysanoptera: Thripidae) discovered in Southern France. Acta Hortic. 952: 785-792.

Poncet C, Lemesle V, Mailleret L, Bout A, Boll R, Vaglio J (2010). Spatiotemporal analysis of plant pests in a greenhouse using a Bayesian approach. Agric. For. Entomol. 12: 325-332.

Priesner H (1964). Ordnung Thysanoptera (Fransenflügler, Thripse). *in* Franz H, Bestimmungsbücherzur Bodenfauna Europas Akademie-Verlag. 2: 242 pp.

Reynaud P, Balmès V, Pizzol J (2008). *Thrips hawaiiensis* (Morgan 1913) (Thysanoptera: Thripidae), an Asian pest thrips now established in Europe. Bulletin OEPP/EPPO. 38: 155-160.

Sauer A (1997). Populationsdynamik von Thysanopteren und Befallsunterschiede bei Rosen im Gewächshaus. Mitt. Deutsch. Ges. Allg. Angew. Entomol. 11: 337-340.

Schliephake G, Klimt K (1979). Thysanoptera,

Fransenflügler. Die Tierwelt Deutschlands. 66:1-477.
Trdan S (2003). Monitoring of western flower thrips (*Frankliniella occidentalis* [Pergande], Thysanoptera) in the vicinity of greenhouses in different climatic conditions in Slovenia. Agricultura, 1(2): 1-6.
Trdan S, Žnidarčič D, Kač M, Vidrih M (2008). Yield of early white cabbage grown under mulch and non-mulch conditions with low populations of onion thrips (*Thrips tabaci* Lindeman). Int. J. Pest Manag., 54:(4)309-318.
Zur Strassen R (2003). Die terebranten Thysanoptera Europas und des Mittelmeer-gebietes. Die Tierwelt Deutschands. 74: 1-277.