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DIVERSITY AND ABUNDANCE OF PHYTOSEIIDAE (ACARI: MESOSTIGMATA) IN THREE CROP MANAGEMENT STRATEGIES OF CITRUS ORCHARDS IN TUNISIA

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ABSTRACT — Surveys of Phytoseiidae were carried out in three Tunisian citrus orchards; the first was conducted according to organic farming practices; the second was conducted according to integrated pest management; the third was conventionally conducted with an intensive use of pesticides. The aim of the present study was to assess Phytoseiidae diversity and densities in these orchards both on trees and weeds. The highest Phytoseiidae diversity on citrus and weeds was observed in the organic citrus orchard (eight species on citrus and eight species on weeds). In the conventionally managed orchard, only three and four species of Phytoseiidae were found on weeds and trees, respectively. The same species, *Euseius stipulatus*, was dominant on citrus in the three orchards, whereas it was observed only on some weeds. The prevalent Phytoseiidae species were different according to the orchards (*Typhlodromus* [*Typhlodromus*] *phialatus* in organic farmed plot, *Neoseiulus californicus* in integrated managed plot and *Phytoseiulus persimilis* in the conventional one). Prevalence of such species was due to their high abundance on some plants (*i.e. Phaseolus vulgaris* for *P. persimilis*). No clear impact of weed management on citrus Phytoseiidae fauna was observed. However, pesticide use seems to affect densities and diversity of Phytoseiidae. Even if no clear correlation between *E. stipulatus* and *Tetranychus* sp. was observed, it seems that *E. stipulatus* could feed on *Tetranychus* sp. but cannot quickly and efficiently control high densities of these pests.

KEYWORDS — citrus; Phytoseiidae; weed management; pesticide; diversity; dynamic; organic; conventional

INTRODUCTION

Eight species of phytophagous mites, belonging to families Tetranychidae, Tenuipalpidae, Eriophyidae and Tarsonemidae are known to cause damages in Tunisian citrus orchards (Kreiter *et al.*, 2002). *Tetranychus urticae* Koch is certainly the most serious pest (Grissa and Khoufi, 2012). Pesticide can be used to control these pests; however because of environmental problems caused by spraying, alternative solutions especially biological control strategies are investigated (Reis *et al.*, 2000; Aceujo *et al.*, 2003; Gerson *et al.*, 2003; Aguilar-Fenollosa *et al.*, 2011). The most efficient natural enemies known to control pest mites belong to the mite family Phytoseiidae (McMurtry and Croft, 1997). Surveys carried out in Tunisian citrus or-

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chards showed the occurrence of eighteen Phytoseiidae species (Kreiter *et al.*, 2010; Sahraoui *et al.*, 2012). The most abundant are: *Euseius stipulatus* (Athias-Henriot), *Iphiseius degenerans* (Berlese), *Neoseiulus californicus* (McGregor), *Phytoseiulus persimilis* Athias-Henriot, *Typhlodromus* (*Anthoseius*) *rhenanoides* Athias-Henriot and *Typhlodromus* (*Typhlodromus*) *phialatus* Athias-Henriot (Sahraoui *et al.*, 2012).

Species diversity and abundance of Phytoseiidae are mainly affected by climate conditions, habitat stability and food resources (McMurtry and Croft, 1997). Most Phytoseiidae are able to survive and develop when preys are absent because of their polyphagous diet (McMurtry and Croft, 1997; Nyrop *et al.*, 1998). This generalist feeding habits (pollen, fungi, and other mites) explain in part the perennial presence of *Typhlodromus* (*Typhlodromus*) *pyri* Scheuten and *Kampimodromus aberrans* (Oudemans) in European vineyards and their ability to control mite pests in such agrosystems (Duso, 1992; Lorenzon *et al.*, 2012). Crop management could also affect Phytoseiidae densities and diversity. Many studies related the negative effects of pesticides on Phytoseiidae (*i.e.* Kreiter *et al.*, 1998; Childers *et al.*, 2001; Chen *et al.*, 2003; Hardman *et al.*, 2006, 2007; Bonafos *et al.*, 2008; Meyer *et al.*, 2009; Peverieri *et al.*, 2009). In surveys comparing treated and untreated apple orchards in North Carolina, Farrier *et al.* (1980) showed that there were two-fold more species on untreated trees compared to treated ones. Surveys carried out by Fitzgerald and Solomon (2001) showed that Christmas tree plantations chemically treated had lower Phytoseiidae densities than the untreated ones. Finally, some authors report the positive impact of agrosystem diversification on natural enemy communities (*i.e.* Altieri and Letourneau, 1982; Tscharntke *et al.*, 2005). Weeds are major components of agrosystems; some authors report that they can affect occurrence of pests and beneficial insects (Altieri *et al.*, 1977). However, only few studies have focused on the effect of weed management practices on Phytoseiidae dynamics. Some studies have shown that herbicides have directly detrimental effects on Phytoseiidae in apple orchards (Rock and Yeargan, 1973; Hislop and Prokopy, 1981), vineyards (Kreiter *et al.,* 1993) and citrus orchards (Pereira *et al.*, 2006; Aguilar-Fenollosa *et al.*, 2008, 2011; Mailloux *et al.*, 2010). Some also shows that weeds can harbor Tetranychidae mites but also Phytoseiidae mites (*i.e.* Muma, 1975; Aceujo *et al.*, 2003; Fenollosa *et al.*, 2008, 2011).

The aim of the present study is to characterize Phytoseiidae diversity and densities in three Tunisian citrus orchards managed with contrasted pesticide and weeding managements.

Materials and methods

Studied orchards

Mite families Phytoseiidae and Tetranychidae were surveyed in three citrus orchards (two in the Cap Bon and one in Bizerte regions) from September 2009 to August 2011.

In the orchard (1) conducted with organic farming practices, only one insecticide (spinosad) was applied in April 2011 to control aphids. The ground cover was dominated by Poaceae and mechanical weeding was done once in April (Table 1). In the orchard (2) conducted according to integrated pest management (one insecticide: imidaclopride applied in April), ground vegetation was diversified and was ploughed once in April (weeds on the rows were not destroyed). In the orchard (3) conventionally conducted eleven pesticides were applied to control several pests and diseases (sulfur, abamectin, malathion, dimethoate, cyhexatin + tetradifon, methyl tiophanate, benomyl, copper, *Bacillus thuringiensis*). Herbicide (glyphosate) was applied two times (in November and March), and ground was ploughed several times. *Phaseolus vulgaris* L. was planted in April as inter-cropping on the rows under the trees (Table 1).

Populations of whiteflies, thrips and scales were present in the three orchards but only few individuals were seen during countings and the densities remained very low during the whole study.

The climate in the Cap Bon and Bizerte regions is semi-arid marked by irregular precipitations and temperate, respectively. During the survey, the

TABLE 1: Characteristics of the three Tunisian citrus orchards considered in the study.

	Location	Citrus species and cultivars	Pesticide sprays	Plantation density (in meters)	Ground cover characteristics	Weeding management
Orchard 1	Cap Bon (Taleska) 36.804° N; 10.602° E	*Citrus clementina* cv. Nour (MA3)	1 spray Spinosad (April)	4 x4	Dominance of Poaceae	Mowing once in April
Orchard 2	Cap Bon (Manzel Bouzelfa) 36.698° N; 10.605° E	*Citrus clementina* cv. Marisol	1 spray Imidacloprid (April)	3.5x 3.5	Varied wild cover, annual species.	Mechanical weeding once in
Orchard 3	Bizerte (Azib Bizerte) 37.213° N; 9.958° E	Citrus limon Burm. f. cv. Eureka	11 sprays	4 x 4	No weeds until May, Been plants in inter-cropping planted in May	Herbicide "glyphosate" and ground ploughed several times

highest temperatures were observed in July-August (ranging between 30 to 38 °C) and the rainfalls were marked from October to May with maximum rainfall observed in November with 15 mm for orchards (1) and (2) and 44 mm for orchard (3).

Mite survey

From September 2009 to August 2010, samplings were conducted at least one time a month. At each sampling date, 30 citrus leaves were randomly taken in each plot. To characterize mite fauna in ground vegetation, two liters of weeds were randomly collected. Then, each plant (weeds) and citrus leaves were transported in freezing boxes to the laboratory for mite extraction. Mites were extracted from citrus leaves and weeds using the 'soaking-checking-washing-filtering method' (Boller 1984). Then all Tetranychidae and Phytoseiidae found were counted and Phytoseiidae were identified at species level. The generic classification of Chant and McMurtry (2007) and specific literature (Ferragut *et al.*, 2009; Papadoulis *et al.*, 2009) were used for species identification. Specimens of Tetranychidae all belong to the genus *Tetranychus*, but no further identification at species level was carried out.

Data analyses

The number of Phytoseiidae species "species richness" and the Simpson diversity index (1 – D) (Simpson, 1949) were calculated to compare diversity on citrus trees and weeds in the three orchards considered. Simpson's diversity index ranges between 0 and 1; a value of 1 represents an infinite diversity and a value of 0, no diversity. Species similarity between the three orchards was estimated using the Jaccard index. This index corresponds to the number of species shared by two orchards divided by the total number of species (Jaccard, 1912). This index ranges from 0 (no common species) to 1 (all species in common).

RESULTS

Time variation of mite density and diversity

Orchard 1. Eight species of Phytoseiidae were found on citrus (Fig. 1a). The most abundant species was *E. stipulatus* (92 %). The highest densities were observed in December (3 individuals / leaf) and May (2 individuals / leaf). Damages of *Tetranychus* sp. were observed, the highest densities (3 individuals / leaf) being observed two weeks before the Phytoseiidae peak. Then, densities of both Phytoseiidae and Tetranychidae decreased until March (Fig. 2). Two smaller peaks of Tetranychidae were observed in March and July (1 individual / leaf).

Phytoseiidae appeared on weeds in March and the highest densities were observed in June. Eight species were found (Fig. 1b; Table 2). Sixty-three percent of Phytoseiidae found were collected on Poaceae, which were dominant in this orchard. Five species are found on citrus and weeds: *E. stipulatus*, *Graminaseius graminis* (Chant), *P. persimilis*, *T.* (*A.*) *rhenanoides* and *T.* (*T.*) *phialatus* (Jaccard index = 0.45). However, the dominant species were different. The dominant species on weeds was *T.* (*T.*) *phialatus* because of its occurrence on four plants: *Elytrigia repens* L., *Hordeum murinum* L., *Chrysanthemum* sp. and *Solanum nigrum* L. *Euseius stipulatus,* prevalent on citrus, was present on four weeds but

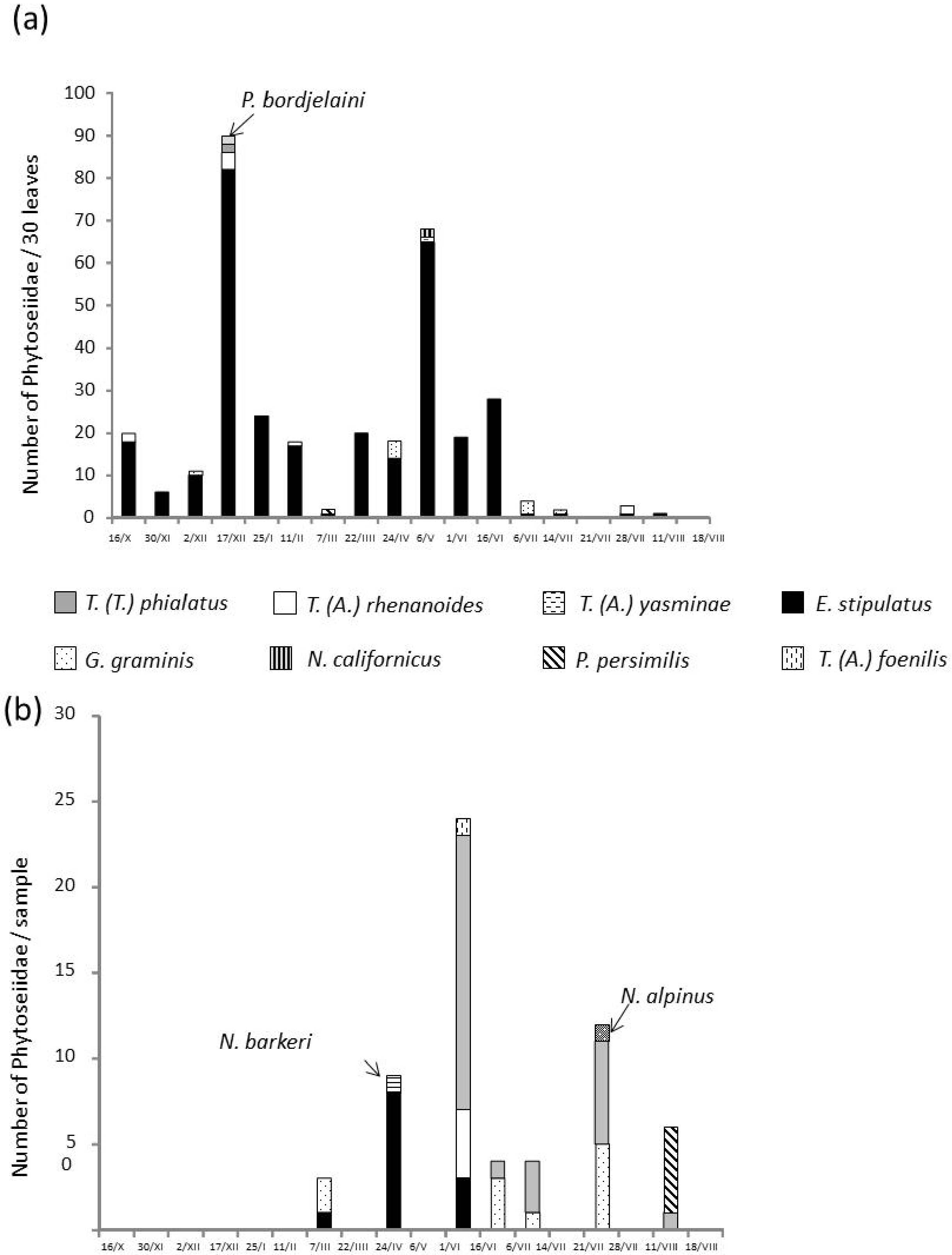

FIGURE 1: Time variation of Phytoseiidae densities and diversity in orchard (1) (a) on citrus leaves, (b) on weeds.

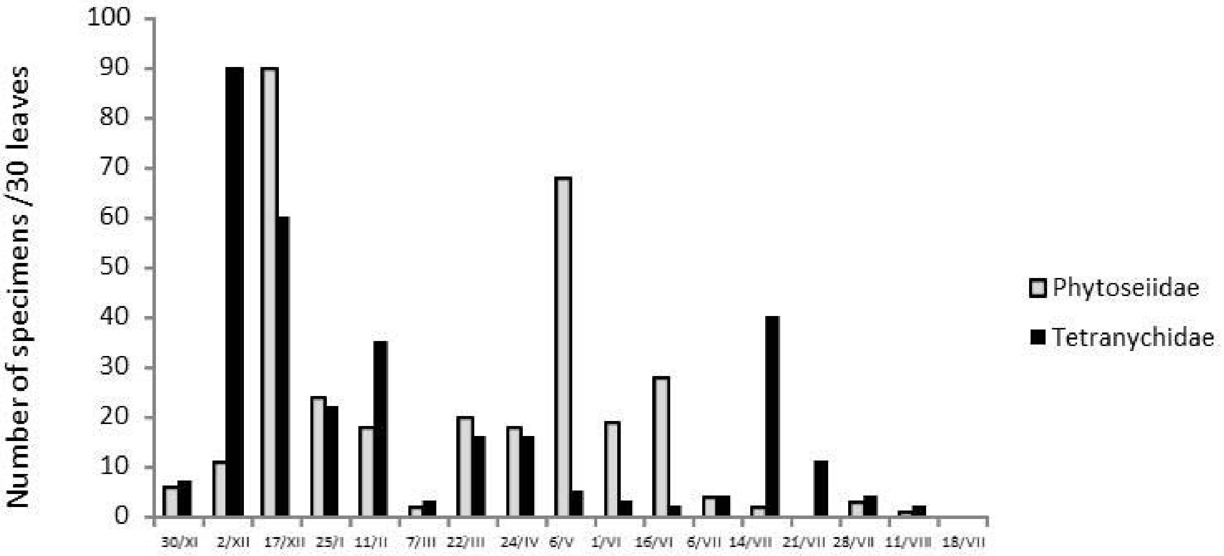

FIGURE 2: Time variation of Phytoseiidae and Tetranychidae densities on citrus leaves in orchard (1).

in very low densities (Table 2). *Tetranychus* sp. were present only at three dates on the same plant (*S. nigrum*).

Orchard 2. Four species of Phytoseiidae were identified on citrus, *E. stipulatus* being dominant (98 %). The highest densities were observed in April (2 individuals / leaf) (Fig. 3a). They then declined progressively to reach low numbers in summer. Few specimens of *Tetranychus* sp. were observed on citrus (4 females/ 30 leaves founded in July).

Eight Phytoseiidae species were found on weeds. The highest density of Phytoseiidae was observed in March (Fig. 3b). Four species are found both on citrus and weeds (*E. stipulatus*, *N. californicus*, *T.* (*A.*) *rhenanoides* and *T.* (*T.*) *phialatus*) (Jaccard index = 0.5). However, as in the orchard (1) the dominant species are different. The prevalent species on weeds was *N. californicus.* This species was mainly collected on *Mercurialis annua* L., and *Malva* sp., the two most abundant plants in the orchard in spring. *Euseius stipulatus*, prevalent on citrus, was observed on three plants in the inter-rows (*Malva* sp., *Convolvulus arvensis* and *S. nigrum*). The highest Tetranychidae densities were also observed in March (129 individuals/ sample) collected mainly on *M. annua*. After weeding, no more Tetranychidae was collected until July.

Orchard 3. Five species of Phytoseiidae were collected on citrus; *E. stipulatus* being the dominant species (79 %). No Tetranychidae was found. The Phytoseiidae densities were very low (always less than 0.25 individual / leaf), the highest numbers being observed between March and May (Fig. 4a).

Seven species of Phytoseiidae were observed on weeds. Four species are found both on citrus and weeds (*E. stipulatus*, *N. californicus*, *P. persimilis* and *T.* (*A.*) *rhenanoides*) (Jaccard index = 0.5). However, the dominant species were different. *Phytoseiulus persimilis* prevailed on weeds (78 %) and was mainly observed on the planted species *P. vulgaris.* The highest densities were observed in July (Table 2). *Euseius stipulatus*, dominant on citrus, was only found on *Malva* sp. Tetranychidae were observed on this plant since June and the highest densities were found in July.

TABLE 2: Species of Phytoseiidae and female numbers (into brackets) found on weeds collected in the three Tunisian citrus orchards.

Plant species	Orchard 1	Orchard 2	Orchard 3
***Malva* sp.**	*G. graminis* (1)	*E. stipulatus* (7) *N. californicus* (51) *P. persimilis* (13) *T.* (*A.*) *yasminae* (1)	*E. stipulatus* (5) *N. californicus* (6) *T.* (*A.*) *foenilis* (2) *T.* (*A.*) *rhenanoides* (3) *P. persimilis* (19)
***Chrysanthemum* sp.**	*E. stipulatus* (1)		
***Solanum nigrum* L.**	*E. stipulatus* (2) *T.* (*A.*) *rhenanoides* (3) *T.* (*T.*) *phialatus* (5) *P. persimilis* (5)	*N. californicus* (11) *E. stipulatus* (7) *N. barkeri* (1) *T.* (*T.*) *phialatus* (1) *P. persimilis* (1) *N. alpinus* (1)	*P. persimilis* (9) *N. californicus* (4)
***Conyza canadensis* L.**	*E. stipulatus* (5) *N. barkeri* (1)		*T.* (*A.*) *rhenanoides* (1) *T.* (*A.*) *recki* (2)
Hordeum murinum L.	*E. stipulatus* (2) *T.* (*T.*) *phialatus* (4) *G. graminis* (7) *N. alpinus* (1)		
***Bromus diandrus* Roth.**			*P. persimilis* (1) *N. californicus* (6) *N. barkeri* (1)
***Amaranthus retroflexus* L.**			*N. californicus* (6) *T.* (*A.*) *rhenanoides* (3)
***Acalypha rhomboidea* Raf.**			*T.* (*A.*) *rhenanoides* (4) *N. californicus* (1)
***Emex spinosa* L.**	*T.* (*A.*) *foenilis* (1) *T.* (*T.*) *phialatus* (4)		
***Salvia officinalis* L.**			*P. persimilis* (3) *N. californicus* (2)
***Cynodon dactylon* (L.) Persoon.**	*T.* (*T.*) *phialatus* (8)		
***Cyperus rotundus* L.**	*T.* (*T.*) *phialatus* (4)		
***Mercurialis annua* L.**		*T.* (*A.*) *rhenanoides* (4) *N. californicus* (67) *E. stipulatus* (1) *T.* (*T.*) *phialatus* (1) *P. persimilis* (2)	
***Phaseolus vulgaris* L.**			*P. persimilis* (163) *N. californicus* (9)
***Convolvulus arvensis* L.**		*E. stipulatus* (14)	
***Rubus* sp.**		*N. californicus* (3) *T.* (*A.*) *rhenanoides* (7)	

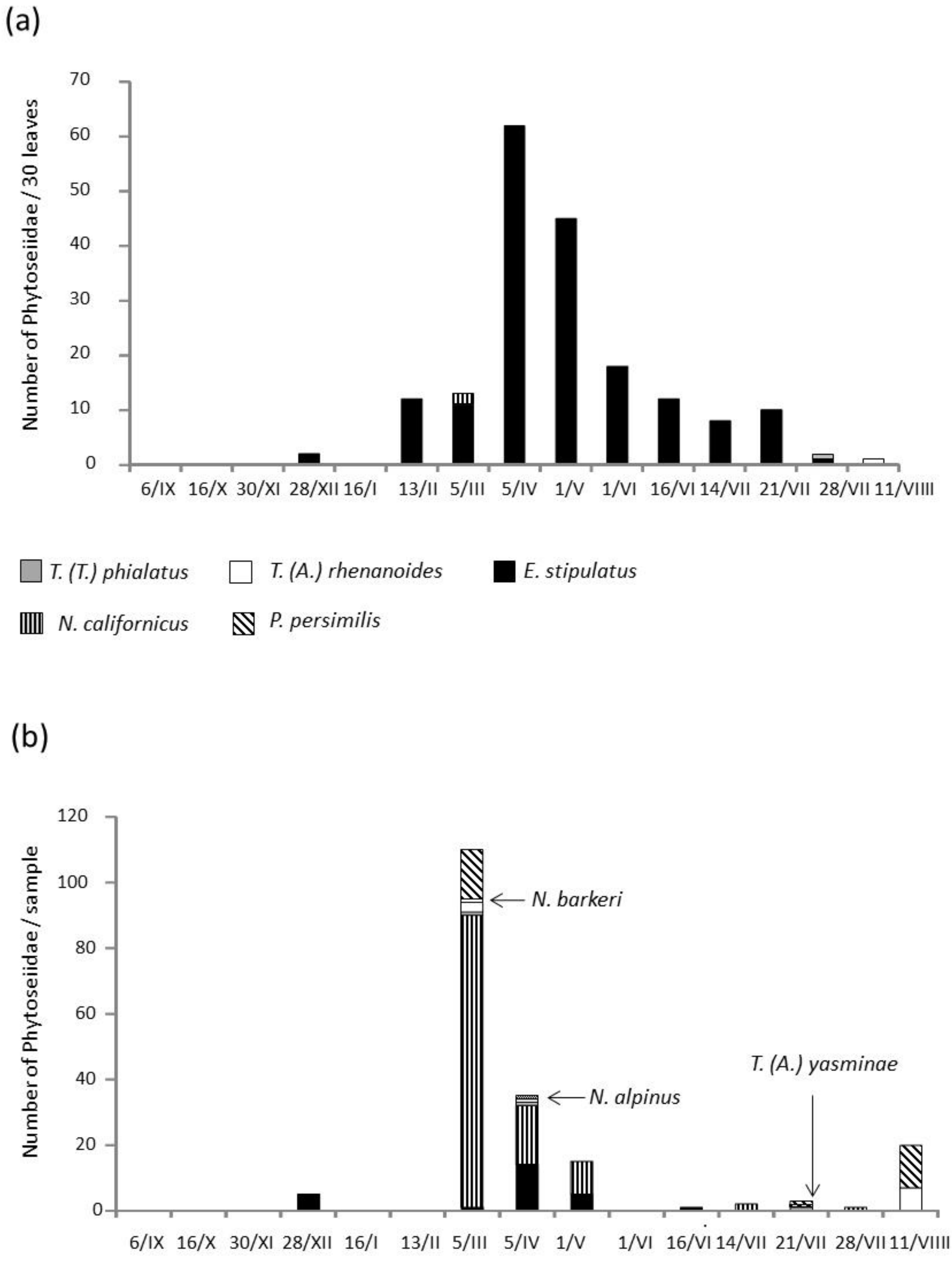

FIGURE 3: Time variation of Phytoseiidae densities and diversity in orchard (2) (a) on citrus leaves, (b) on weeds.

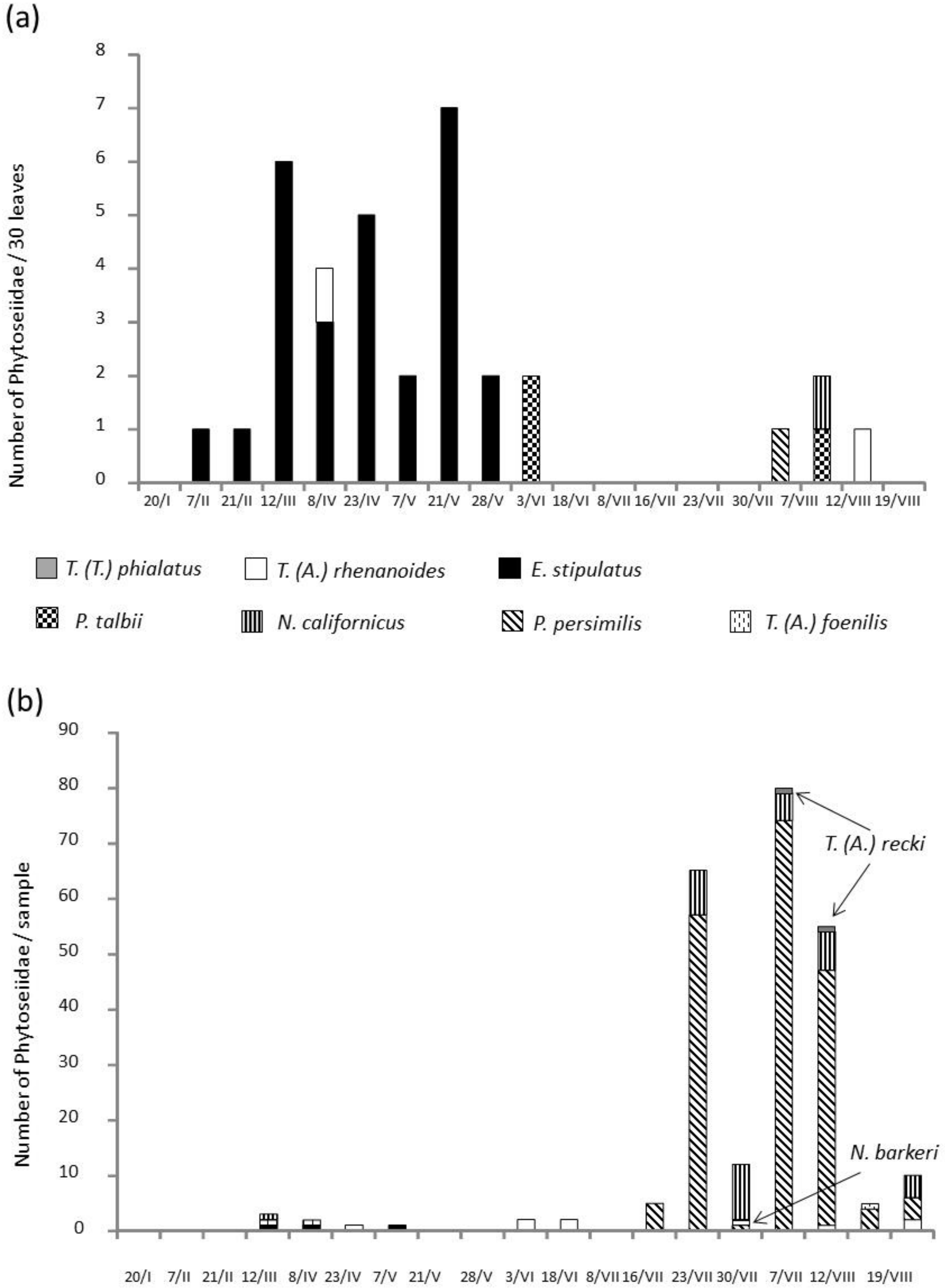

FIGURE 4: Time variation of Phytoseiidae densities and diversity in orchard (3) (a) on citrus leaves, (b) on weeds.

TABLE 3: Proportion (%) of species of Phytoseiidae observed in the three Tunisian citrus orchards, on trees and weeds and Diversity (1-D) indices.

	weeds			citrus		
	orchard 1	**orchard 2**	**orchard 3**	**orchard 1**	**orchard 2**	**orchard 3**
Euseius stipulatus	18.5	15.1	2	92.2	97.8	79.4
Graminaseius graminis	14.8	0	0	2.7	0	0
Neoseiulus alpinus	1.9	0.5	0	0	0	0
Neoseiulus barkeri	1.9	0.5	0.4	0	0	0
Neoseiulus californicus	0	68.4	13.6	0.6	1.1	2.9
Paraseiulus talbii	0	0	0	0	0	8.8
Phytoseiulus persimilis	9.3	8.3	78	0.3	0,0	2.9
Proprioseiopsis bordjelaini	0	0	0	0.6	0	0
Typhlodromus (A.) foenilis	1.9	0	0.8	0	0	0,0
Typhlodromus (A.) recki	0	0	0.8	0	0,0	0,0
Typhlodromus (A.) rhenanoides	5.6	5.7	4.4	2.7	0.5	5.9
Typhlodromus (A.) yasminae	0	0.5	0,0	0.3	0	0
Typhlodromus (T.) phialatus	46.3	1.0	0	0.6	0.5	0
Number of species	8	8	7	8	4	5
1-D	0.71	0.55	0.37	0.15	0.04	0.37

Orchard comparison

Phytoseiidae on Citrus trees. Even if no statistical analyses can be carried out, some tendency on Phytoseiidae densities can be drawn. The highest densities of Phytoseiidae were observed in the orchard (1) and the lowest in the orchard (3). The highest number of Phytoseiidae species was also observed in the orchard (1). However, in the three orchards, the same species *E. stipulatus* prevailed. *Euseius stipulatus*, *N. californicus* and *T.* (*A.*) *rhenanoides* were present in the three orchards. *Typhlodromus* (*T.*) *phialatus* was found in the orchards (1) and (2), *P. persimilis* in the orchards (1) and (3) whereas *Graminaseius graminis* (Chant), *Typhlodromus* (*Anthoseius*) *yasminae* Faraji and *Proprioseiopsis bordjelaini* (Athias-Henriot) were found only in the orchard (1) and *Paraseiulus talbii* (Athias-Henriot) only in the orchard (3). Jaccard index between orchards (1) and (2) is the highest (0.6) whereas between orchards (1) and (3) and orchards (2) and (3) this index is of 0.4. Even if the species richness was higher in the orchard (1), Simpson indices are low in the three orchards (Table 3), because of the great prevalence of *E. stipulatus*.

Phytoseiidae on weeds. Phytoseiidae diversity (1 – D) was higher in orchard (1) than in the two other ones whereas species richness is equivalent (Table 3). Furthermore, in this orchard, Phytoseiidae richness was similar on citrus trees and weeds, whereas in the two other ones the number of Phytoseiidae species was higher on weeds than on citrus (Table 3). Four Phytoseiidae species were observed in the ground cover of the three orchards: *P. persimilis*, *Neoseiulus barkeri* Hughes, *T.* (*A.*) *rhenanoides* and *E. stipulatus*. Dominant species in weeds were different according to orchards (*E. stipulatus* in orchard [1], *N. californicus* in orchard [2] and *P. persimilis* in orchard [3]). Jaccard indices are of 0.5 between orchards (1) and (2), orchards (2) and (3) and of 0.44 between orchards (1) and (3).

Tetranychidae occurrence. Variation in time of Tetranychidae was different in the three orchards, on citrus trees and weeds. Tetranychidae were abundant on citrus in orchard (1) and nearly absent in the two others. In the ground cover of orchard (1), Tetranychidae were sporadically present but always on the same plant (*S. nigrum*). Tetranychidae were abundant in the ground cover of the orchard (3) on *P. vulgaris* and *Amaranthus retroflexus* L. In orchard (2), Tetranychidae were mainly observed in March especially from *M. annua*.

Discussion

Phytoseiidae species found and their biological control efficiency

Among the thirteen Phytoseiidae species collected in this survey, five were found in the three orchards: *E. stipulatus, P. persimilis*, *N. barkeri*, *N. californicus* and *T.* (*A.*) *rhenanoides.* The majority of these species are, according to McMurtry and Croft's classification (1997), generalist predators that feed on a great variety of food sources including mites, insects, pollen ... This may explain their high abundance in absence of pest preys.

Euseius stipulatus was the dominant species on citrus trees in the three orchards. This species also prevails in other citrus orchards in Tunisia (Sahraoui *et al.*, 2012), Spain (Pereira *et al.*, 2006; Abad-Moyano *et al.*, 2009, 2010) and in the Mediterranean citrus orchards in general (McMurtry, 1977). *Euseius stipulatus* was found even when Tetranychidae were absent. This species is considered according to McMurtry and Croft (1997) as specialized pollen feeder (Type 4). Several authors reported that its development rate is higher fed on pollen than on phytophagous mites (*i.e.* Ferragut *et al.*, 1987, Zhimo and McMurtry, 1990). Furthermore, some studies have shown that its occurrence could be related to pollen abundance (Villanueva and Childers, 2004). The abundance of *E. stipulatus* in spring (in the three orchards) could thus be due to the presence of pollen. However, in orchard (1), this species was also abundant in December whereas pollen quantity was low. This species is also known to feed on *Panonychus citri* (McGregor) (Ferragut *et al.*, 1988, 1992), *T. urticae* (Abad-Moyano *et al.*, 2009) and eriophyid mites (Ferragut *et al.*, 1987). Its abundance in December could thus be due to the occurrence in orchard (1) of specimens of *Tetranychus* sp., of eriophyid mites, or tydeid mites (which are abundant during this period) suggesting that this species could feed on these preys in citrus orchards. This species was present throughout the year during the surveys except in summer (July-August) when the temperature exceeds 30 – 35 °C. Ferragut *et al.* (1987) showed that this species stops laying eggs at 32 °C.

Among the other Phytoseiidae species present on citrus trees, *N. californicus* and *P. persimilis* can be considered as good candidates for biological control of phytophagous citrus. *Phytoseiulus persimilis* is known as a specialist predator, especially efficient to control *T. urticae* in greenhouses all over the world (McMurtry and Croft, 1997).

Neoseiulus californicus is reported to control mites of the family Tetranychidae (Escudero *et al.*, 2004; Greco *et al.*, 2005; Katayama *et al.*, 2006; Gomez *et al.*, 2009), but can also consume other mite species as *Phytonemus pallidus* (Banks) (Easterbrook *et al.*, 2001) and small insects, as Thripidae (Rodriguez *et al.*, 1992).

Typhlodromus (*A.*) *rhenanoides* is a generalist species, but also reported to reproduce and develop on *T. urticae* and the red mite *P. citri* (Tsolakis *et al.*, 2012), two pest mites of citrus in Tunisia (Grissa and Khoufi, 2012).

In regards to *N. barkeri*, this species is known to control *Frankliniella occidentalis* (Pergande) (Rodriguez-Reina *et al.*, 1992) and *Thrips tabaci* (Lindeman) (Hansen, 1988; Desgaard *et al.*, 1992). Yet, these thrips species are commonly reported in Tunisian citrus orchards (Belaam and Boulahia, 2012).

Even if the three species *P. persimilis*, *N. californicus* and *T.* (*A.*) *rhenanoides* are known to feed on some citrus pests, their densities in the present surveys were too low to play a key role in biological control.

Relations between mite fauna on weeds and on trees

Some authors suggested that the ground cover plants may serve as overwintering plant hosts and provide alternative food for predacious mites (Childers, 1994; Fadamiro *et al.*, 2009). Phytoseiidae were presently found on weeds in all the orchards. However, the prevailing Phytoseiidae species on weeds and citrus were different. Furthermore, no clear correlation between the number of Phytoseiidae on trees and weeds was observed. Whatever the dominant species on weeds (*T.* (*T.*) *phialatus* in orchard: 1) *N. californicus* in orchard, 2) and *P. persimilis* in orchard 3), *E. stipulatus* was the prevailing species in the associated citrus trees. This study does not show clear and abundant exchange between weeds and citrus fauna. Exchanges could nevertheless exist but as shown by Abad-Moyano *et al.* (2010), *P. persimilis* and *N. californicus* could not settle on citrus because of the presence of *E. stipulatus*. Finally, *E. stipulatus* was found on some weeds (*Conyza canadensis*, *Convolvulus arvensis*, *Malva* sp. and *S. nigrum*) in all the orchards and exchange between these plants and citrus could be hypothesized.

Considerations on weed management effects

Phytoseiidae species richness was equivalent on weeds of the three orchards whereas diversity was higher in the orchard (1). This is certainly due to favorable plants present in the inter-rows. Indeed, in the orchards (2) and (3), only one or two plants harbored great quantities of *N. californicus* and *P. persimilis,* respectively. In the orchard (1), the prevalent species *T.* (*T.*) *phialatus* was found on various plants. The Phytoseiidae densities were much lower in weeds of orchard (1) than in the two other orchards. However, this abundance is due to the high densities of *N. californicus* on *M. annua* and *Malva* sp. in March and that observed in orchard (3) is due to the high densities of *P. persimilis* on *P. vulgaris* in July and August. Weeding management can certainly affect Phytoseiidae density and diversity by affecting the plant diversity in inter-rows. Indeed, the ground cover of orchard (1) was mainly composed of Poaceae, known to be poorly colonized by Phytoseiidae (Moraes *et al.*, 1986). The plantation of *P. vulgaris* in orchard (3) favored the occurrence of *P. persimilis*. One can wonder how weed management can affect the abundance of mite pests. *Tetranychus* sp. was abundant on *P. vulgaris* in orchard (3) but poorly observed on citrus trees. On the other hand, very few *Tetranychus* sp. were found on weeds of orchard (1) whereas they were abundant on citrus. Thus no clear effect of weed management on *Tetranychus* sp. has been noted.

Considerations on orchard management effects

In the organic managed orchard (1), the species richness both on citrus and weeds was higher than in the two others. This agrees with other studies showing that arthropod diversity is higher in organic farming systems (*i.e.* Altieri and Nicholls, 2004; Bengtsson *et al.*, 2005; Hole *et al.*, 2005). However, it is also the unique orchards where despite Phytoseiidae occurrence damages of *Tetranychus* sp. have been observed.

The very low numbers of Phytoseiidae on citrus in the orchard (3) with extensive use of pesticides is certainly due to negative effects of pesticides. Pratt and Croft (2000) showed for instance, that insecticides were highly toxic for Phytoseiidae. Pyrethroids, which are known to be highly toxic to predacious mites (Hardmann *et al.*, 2007; Bostanian *et al.*, 2012), were used in the orchard (3). Moreover, applications of some fungicides including benomyl and sulfur could negatively impact Phytoseiidae densities (Childers and Enns, 1975). In addition, the lower densities in orchard (2) in regards to orchard (1) could be due to the use of imidaclopride (in orchard [2]), known to be toxic for Phytoseiidae (Bostanian *et al.*, 2010).

Conclusion

The objective of this study was to assess the total abundance, species richness, and composition of Phytoseiidae and Tetranychidae in different farming systems and to examine the contributions of the vegetation present on Phytoseiidae abundance and composition. Our results provided a detailed picture of the mite community of Tunisian orchards and increase the knowledge of acarofauna associated with this crop. Low pesticide applications were correlated to high diversity and densities of Phytoseiidae on citrus. However, these high densities were not sufficient to limit *Tetranychus* damages. On the other hand, in treated orchards, densities and diversities of predators were lower but no damage was observed. Other factors than pesticide could explain Tetranychidae outbreaks in orchards colonized by a non-specialist predator of these mites: citrus variety (Grissa and Khoufi, 2012), rootstock (Bruessow *et al.*, 2010) and nutritive stress of plants (Aucejo-Romero *et al.*, 2004). Yet, little is known of such effects that it would be interesting to better characterize. Phytoseiidae were present in weeds, suggesting that they can constitute reservoirs for these predators. However, *E. stipulatus* prevailing on citrus were poorly present on weeds, wondering the impact of such a reservoir on pest regulation on trees. More than the impact of weeding management, the most important point seems to determine what would the best plant species in the inter-row to ensure high densities of the Phytoseiidae species also found on trees. According to the present results, it seems that *Malva* sp., *Convolvulus arvensis* and *S. nigrum* could be interesting. However, many questions remain to better manage weed to improve biological control on associated trees. For example, is there Phytoseiidae migration between weeds and trees? How do weed management affect this migration? Further studies are thus planned to answer these questions.

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