Influence of four soil maintenance practices on Collembola communities in a Mediterranean vineyard

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KEYWORDS
Collembola;
Vineyard;
Soil maintenance practices;
Soil samples

Summary

We studied the influence of four soil maintenance practices on Collembola communities in the soil of a Mediterranean vineyard: (a) postemergence herbicide with glyphosate; (b) postemergence and pre-emergence herbicides with glyphosate, terbuthylazine, diuron and oryzalin; (c) natural flora and (d) tillage to a depth of 10–15 cm. Total Collembola abundance, species diversity and species richness significantly varied between the four practices. Notably, the practice using postemergence and pre-emergence herbicides had significantly lower values. Identification of Collembola at species level allowed an interspecies comparison and revealed significant differences for the most common species between the four practices, with each practice being characterized by a different set of species. None of the species were found to be significantly more abundant in the plots treated with postemergence and pre-emergence herbicides.

Introduction

Microarthopods are frequently used as bioindicators in agroecosystems; however, most existing studies have been carried out in old fields and arable crop monoculture systems, for example, maize or crop rotation systems (Wiegert, 1974; Loring et al., 1981; Moore et al., 1984; Dekkers et al., 1994; Cortet and Balaguer-Poinsot, 2000; Alvarez et al., 2001). Few studies have focused on the soil fauna of vineyards (Favretto et al., 1992). The majority of studies have focused on understanding pest damage or on increasing wine quality, and the biological aspect of the matrix which supports wine production is not well understood. Further, there are a number of factors specific to Mediterranean vineyard soils that make a potential study of their fauna interesting. These include high copper concentrations due to fungicides, low organic matter levels and strong impact of seasonality, notably a very dry summer.

There is an increasing awareness of declining soil fertility in French vineyards (notably in the south of France). This decline results from treatment and addition of soil maintenance practices, such as tillage, herbicide, chemical fertilizers, which tend to exhaust soil fertility when used over long periods. Wine growers now seek for management practices which restore soil fertility and which cause less damage to agroecosystems. These "sustainable practices" include natural flora practices in which no herbicides are applied, or the application of postemergence herbicides.

In this experiment, we compared the effects of four types of weed management on collembolan populations in a Mediterranean vineyard. The practices were each conducted in the inter-row spaces of several plots and consisted of (a) postemergence herbicide addition, (b) postemergence plus pre-emergence herbicide addition, (c) grassy inter-row spaces with natural flora and (d) superficial tillage.

Materials and methods

Experimental site

The experimental site was a Mediterranean vineyard called "le Domaine de Donadille" situated at Rodilhan, near Nîmes (southern France). The climate is typically Mediterranean with a dry and hot summer, and the main precipitation in spring and autumn. During the study period, monthly precipitation varied between 1 mm (December 2001) and 109 mm (January 2001). Monthly mean temperatures varied between 4.5 °C (December 2001) and 24.5 °C (August 2001).

Table 1. Sampling dates and details of the application of the four soil maintenance practices

Dates	POST Postemergence herbicide	PRE Postemergence and pre-emergence herbicides	FLOR Natural flora	TIL Superficial tillage
14/04/2000				Tooth tool
18/04/2000	Glyphosate (15 l ha^{-1})	Glyphosate (15 l ha^{-1})+diuron and terbuthylazine (4 l ha^{-1})+oryzalin (6 l ha^{-1})	Mower	
11/05/2000				Tooth tool
28/06/2000	Glyphosate (3.5 l ha^{-1})		Mower	
12/12/2000		Sampling		
16/01/2001		Sampling		
15/02/2002		Sampling		
16/03/2003		Sampling		
17/04/2004		Sampling		
			Mower	
18/04/2001	Glyphosate (15 l ha^{-1})	Glyphosate (15 l ha^{-1})+diuron and terbuthylazine (4 l ha^{-1})+oryzalin (6 l ha^{-1})		
22/05/2004		Sampling		
23/05/2001				Tooth tool
21/06/2001		Sampling		
10/08/2001			Mower	
24/11/2001		Sampling		
12/01/2002		Sampling		
02/03/2002		Sampling		
20/04/2002		Sampling		
15/05/2002	Glyphosate (15 l ha^{-1})	Glyphosate (15 l ha^{-1})		
27/05/2002			Mower	
12/06/2002		Diuron and terbuthylazine (4 l ha^{-1})		
15/06/2002		Sampling		

The vineyard was planted with 15–20 year old Syrah variety vine plants in a silt-clay soil. Each soil maintenance practice was conducted in two plots. The plots were lined up behind others. A plot (15 m long and 7.5 m wide) was composed of four rows of 15 vine plants, separated by three inter-row spaces. In the practice with a postemergence herbicide (POST), only glyphosate was applied. In the practice with postemergence and pre-emergence herbicides (PRE), glyphosate (postemergence herbicide), terbuthylazine, diuron and oryzalin (pre-emergence herbicides) were applied. In the tillage practice (TIL), tillage was carried out with a tooth tool to a depth of 10–15 cm, and no herbicides were applied. In the natural flora practice (FLOR), weeds were cut with a mower and no herbicides were applied. Table 1 shows the application dates of each soil maintenance practice. Following the wine harvest, no treatments were applied until April. The maintenance practices began from mid-April to the end of June. Other treatments (insecticides, fungicides, fertilizers) were identical for all plots. With the exception of the PRE treatment, there was a regrowth of weeds in the inter-row spaces during winter. The FLOR treatment had a weed cover throughout the year.

Sampling methods

Sampling took place between December 2000 and June 2002; no samples were taken in summer due to drought. On each sampling date, six soil samples were taken from the central inter-row space of each treatment plot. Each sample consisted of 400 cm^3 of soil, removed using a small shovel to a depth of 10 cm. The high proportion of pebbles in the soil prevented the use of a core sampler. Soil samples were transported to the laboratory in hermetic bags. The extraction lasted 15 days in a Tullgren apparatus (Tullgren, 1918).

Analysis of data

Total abundance, species diversity (Shannon–Wiener index), species richness (number of species) and species abundance of the most common species found were calculated and then analysed by ANOVA (Statistica software, version 5.1, Statsoft, 1998).

Table 2. Mean density (md, ind m^{-2}) and standard deviation (s.d.) of Collembola species in vineyards with different soil maintenance practices: (a) postemergence herbicide (POST), (b) postemergence and pre-emergence herbicides (PRE), (c) natural flora (FLOR), and (d) superficial tillage (TIL)

Taxa	POST		PRE		FLOR		TIL	
	md	s.d.	md	s.d.	md	s.d.	md	s.d.
Ceratophysella denticulata (Bagnall, 1941)	324.75	7.27	67.23	2.37	658.17	9.33	2544.23	53.89
Cryptopygus thermophilus (Axelson, 1900)	610.03	10.63	72.54	4.36	5.31	0.20	191.08	5.71
Cyphoderus albinus (Nicolet, 1841)	0.00	0.00	0.00	0.00	1.77	0.12	0.00	0.00
Entomobrya lanuginosa (Nicolet, 1841)	272.72	5.89	49.54	1.01	313.16	4.44	102.62	2.02
Entomobrya multifasciata (Tullberg, 1871)	0.00	0.00	0.00	0.00	0.00	0.00	1.77	0.12
Entomobrya unostrigata (Stach, 1930)	10.77	0.41	7.08	0.37	14.15	0.72	40.69	1.23
Folsomides parvulus (Stach, 1922)	14.01	0.40	0.00	0.00	0.00	0.00	84.08	3.51
Isotomiella minor (Schäffer, 1896)	5.38	0.26	1.77	0.12	0.00	0.00	30.08	0.72
Lepidocyrtus cyaneus (Tullberg, 1871)	14.35	0.36	33.62	0.69	42.46	1.39	83.16	1.54
Megalothorax minimus (Willem, 1900)	0.00	0.00	0.00	0.00	3.54	0.17	5.31	0.26
Mesaphorura krausbaueri (Börner, 1901)	401.90	7.73	28.31	0.68	10.62	0.40	26.54	0.58
Neotullbergia ramicuspis (Gisin, 1953)	3.59	0.17	1.77	0.12	0.00	0.00	5.31	0.26
Odontella (Xenyllodes) bayeri (Kseneman, 1935)	0.00	0.00	3.54	0.17	0.00	0.00	0.00	0.00
Orchesella quinquefasciata (Bourlet, 1843)	0.00	0.00	0.00	0.00	17.69	0.70	15.92	0.84
Pseudosinella alba (Packard, 1873)	1.79	0.12	0.00	0.00	19.46	0.87	56.62	1.30
Pseudosinella octopunctata (Börner, 1901)	7.18	0.29	0.00	0.00	15.92	0.47	26.54	0.53
Pseudosinella petterseni (Börner, 1901)	8.97	0.39	1.77	0.12	12.38	0.38	7.08	0.29
Seira ferrarii (Parona, 1888)	93.30	3.89	10.62	0.71	15.92	0.37	1.77	0.12
Sminthurides assimilis (Krausbauer, 1898)	206.33	4.72	373.32	8.95	212.31	5.05	79.62	1.65
Sminthurinus elegans (Fitch, 1863)	186.60	3.30	28.31	0.68	408.70	8.12	15.92	0.47
Sminthurinus niger (Lubbock, 1868)	3.59	0.24	1.77	0.12	12.38	0.38	0.00	0.00
Sminthurus viridis (Linnaeus, 1758)	71.77	2.43	8.85	0.26	35.39	0.84	35.39	0.74
Sphaeridia pumilis (Krausbauer, 1898)	1227.24	20.20	100.85	2.85	2321.30	28.10	122.08	2.71
Sphyrotheca multifasciata (Reuter, 1881)	21.53	1.31	0.00	0.00	0.00	0.00	3.54	0.24

Table 3. Total abundance (mean number of individuals per sample), species diversity (mean Shannon–Wiener index per sample) and species richness (mean number of species per sample) of Collembola in vineyards with different soil maintenance practices

	POST		PRE		FLOR		TIL		*P*
Total abundance	27.37 ab	*3.66*	6.20 c	*1.32*	32.35 a	*4.19*	27.32 b	*6.35*	<0.0001
Species diversity	1.01 a	*0.08*	0.48 b	*0.07*	1.04 a	*0.07*	1.03 a	*0.09*	<0.0001
Species richnes	3.22 a	*0.25*	1.47 b	*0.16*	3.44 a	*0.21*	3.31 a	*0.22*	<0.0001

Significant differences between treatments are marked by different letters. Values in italics are standard errors. (one-way ANOVA, Tukey's HSD test, $P<0.05$, $n=72$). See Table 2 for legend.

The abundance values were log(x+1) transformed in order to homogenize variance and to obtain a normal distribution. Tukey's HSD test (honestly significant difference test) was used as post hoc test.

Results

We found 6686 Collembola in total and 24 species throughout the sampling period (Table 2). Most Collembola species were present at low abundances and occurred in less than 10% of the samples. Only nine species were found in more than 10% of all samples.

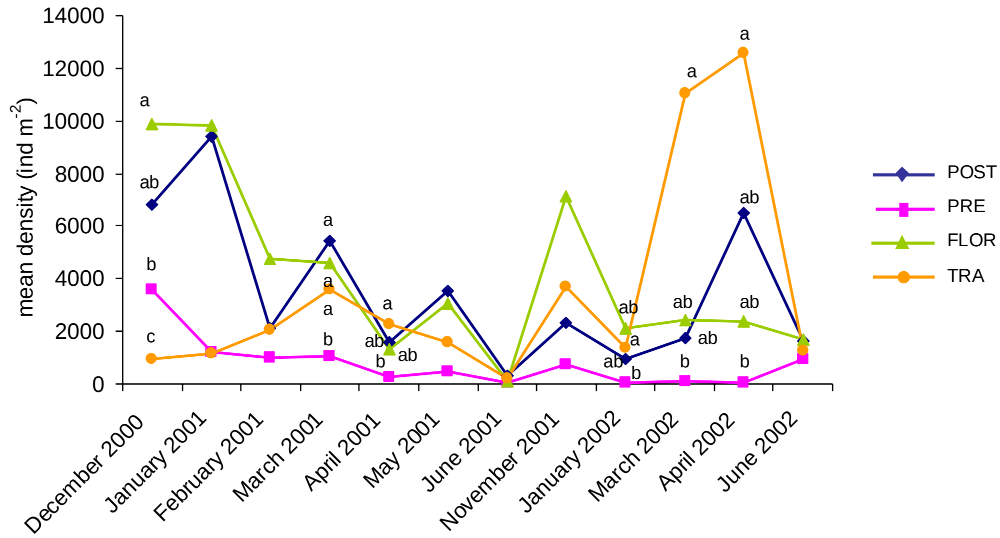
Total abundance was significantly higher throughout the whole sampling period in FLOR than in TRA and PRE, and higher in POST and TRA than in PRE (Table 3). Species diversity and species richness were significantly lower in PRE than in the other treatments (Table 3). There were large seasonal fluctuations in the monthly values of the three indexes, with lower values in summer (Fig. 1). Differences between practices were not significant for every sampling date, notably the Shannon–Wiener index, where the differences between practices were only significant in April 2002 (Fig. 1). PRE actually had the lowest values for all indices, except for total abundance in December 2000 and species diversity in March 2001 (Fig. 1).

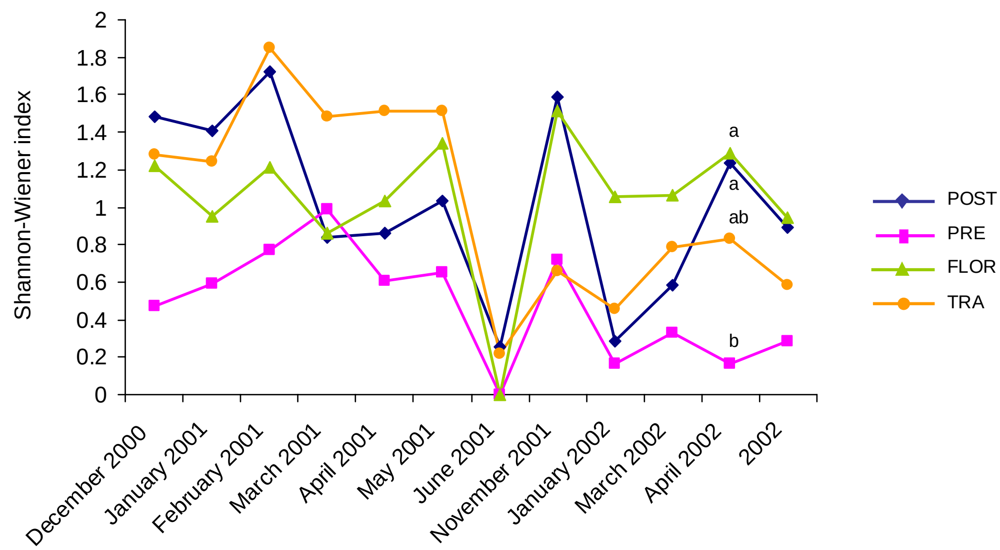
Although total Collembola abundance was significantly higher in FLOR and lower in PRE, responses of the most common species to the various practices varied widely. During the whole sampling period *Entomobrya lanuginosa*, *Sminthurinus elegans* and *Sphaeridia pumilis* were more abundant in samples from FLOR, whereas the density of *Cryptopygus thermophilus*, *Mesaphorura krausbaueri* and *S. viridis* was highest in POST (Table 4). *Ceratophysella denticulata* and *Lepidocyrtus cyaneus* were more abundant in TIL (Table 4). The significance of the difference between the plots for the individual species abundances was tested for each date. Only *Sminthurides assimilis* was not significantly influenced by soil maintenance practices at any date during the whole sampling period. The density of common species fluctuated with season (Fig. 2): *C. denticulata, C. thermophilus, E. lanuginosa and M. krausbaueri* were numerous in spring, while *S. assimilis, S. elegans* and *S. pumilis* were numerous in winter.

Discussion

The PRE practice had the lowest values of total abundance, species diversity and richness of Collembola communities, while the total abundance was highest in FLOR and POST practices. The principal difference between the four treatments was the presence or absence of weed cover. This was completely destroyed (PRE), partially destroyed but left undisturbed in winter (POST and TIL), and left undisturbed throughout the year (FLOR). The absence of weed cover appears to have prevented the development of a favourable microclimate for Collembola. Further, this had a greater impact than the physical stress created by the

Figure 1. Changes in (a) density of Collembola (ind m^{-2}), (b) species diversity (mean Shannon–Wiener index per sample), and (c) species richness (mean number of species per sample) of Collembola from each of the four soil maintenance practices (POST=postemergence herbicide, PRE=postemergence and pre-emergence herbicides, FLOR=natural flora and TIL=superficial tillage). Significant differences between means at each sampling date are marked by different letters (one-way ANOVA, Tukey's HSD test, $P<0.05$).


mean density (ind m-2)
14000
12000
10000
8000
6000
4000
2000
0
December 2000
January 2001
February 2001
March 2001
April 2001
May 2001
June 2001
November 2001
January 2002
March 2002
April 2002
June 2002
POST
PRE
FLOR
TRA
(a)


Shannon-Wiener index
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
December 2000
January 2001
February 2001
March 2001
April 2001
May 2001
June 2001
November 2001
January 2002
March 2002
April 2002
2002
POST
PRE
FLOR
TRA
(b)

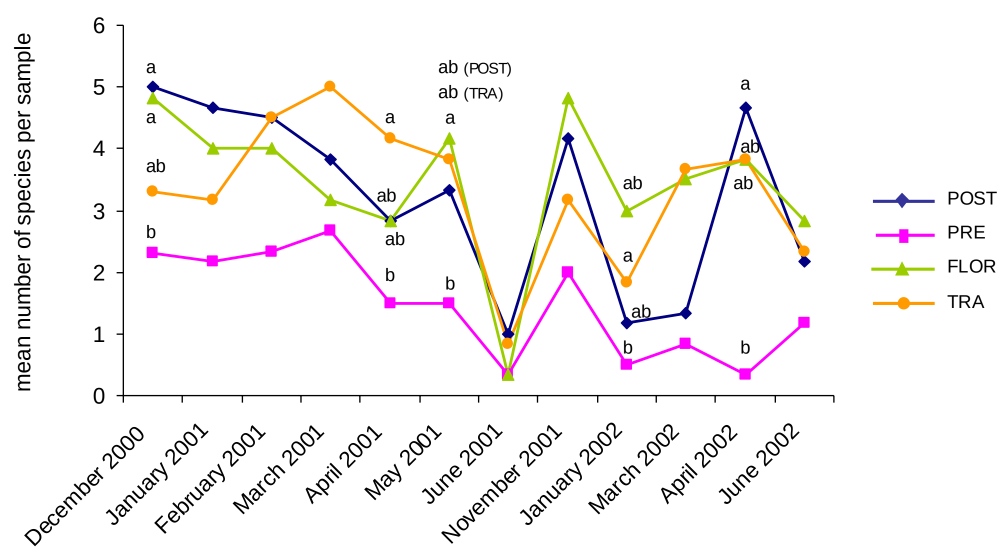

mean number of species per sample
6
5
4
3
2
1
0
ab (POST)
ab (TRA)
December 2000
January 2001
February 2001
March 2001
April 2001
May 2001
June 2001
November 2001
January 2002
March 2002
April 2002
June 2002
POST
PRE
FLOR
TRA
(c)

Table 4. Abundance (mean number of individuals per sample) of Collembola in vineyards with different soil maintenance practices

	POST		PRE		FLOR		TIL		*P*
C. denticulata	2.54 c	*0.86*	0.52 d	*0.28*	5.16b	*1.10*	19.97 a	*6.35*	<0.0001
C. hermophilus	4.78 a	*1.26*	0.56 bc	*0.51*	0.04 b	*0.02*	1.50 c	*0.67*	<0.0001
E. Lanuginosa	2.14 b	*0.70*	0.38 c	*0.12*	2.45 a	*0.52*	0.80 bc	*0.24*	<0.0001
L. cyaneus	0.11 b	*0.04*	0.26 b	*0.08*	0.33 b	*0.16*	0.65 a	*0.18*	<0.0022
M. krausbaueri	3.15 a	*0.92*	0.22 b	*0.08*	0.08 b	*0.05*	0.20 b	*0.07*	<0.0001
S. assimilis	1.61 a	*0.56*	2.93 a	*1.05*	1.66 a	*0.60*	0.62 a	*0.19*	Ns
S. elegans	1.46 b	*0.39*	0.22 c	*0.08*	3.20 a	*0.96*	0.12 c	*0.06*	<0.0001
S. viridis	0.56 a	*0.29*	0.06 b	*0.03*	0.27 ab	*0.10*	0.27 ab	*0.09*	<0.0402
S. pumilis	9.63 b	*2.40*	0.79 c	*0.34*	18.22 a	*3.31*	0.95 c	*0.32*	<0.0001

Significant differences between treatments are marked by different letters. Values in italics are standard error (one-way ANOVA, Tukey's HSD test, $P<0.05$, $n=72$). See Table 2 for legend.

tillage, which is known to damage soil arthropod communities (Moore et al., 1984; Mallow et al., 1985). Weed cover may function as a source of organic matter, as a source of nutrients for microorganisms and microarthropods through decomposition of leave covers and rhizosphere (Garrett et al., 2001), as thermal and hygric protection of soil against sun and rain, and as refuges against predation for epigeic forms. In addition, the abundant root system provides greater soil aeration, lower bulk density and tunnels in the soil.

The biological activity of soil fauna was studied by Reinecke et al. (2002) using the bait-lamina method, under post- and pre-emergence herbicides in a vineyard of South Africa. They showed that biological activity was higher in the plots treated with postemergence herbicides than in the control plots or in plots treated with pre-emergence herbicide. The indirect effect of the postemergence herbicide, a supply of dead organic matter, was greater than the potential toxic effect of this herbicide. Sturm et al. (2002), working in a Dutch vineyard, showed higher biological activity and Collembola abundance in inter-row spaces with grass cover than in inter-row spaces with bare soil. They concluded that mowing grass twice per year provided a substantial amount of resources for the soil fauna. In both of these studies, as in our study, the presence of grass, even if postemergence herbicides are applied, had a beneficial effect on the soil fauna when compared to bare soil.

Our results suggest that a high taxonomic resolution is essential for detecting the effect of agricultural perturbation on soil Collembola. The POST practice and the FLOR practice favoured the development of epigeic and hemiedaphic species, due to preservation of the weed cover. *C. denticulata* and *L. cyaneus* were favoured in TIL practice. *L. cyaneus* was also found by Renaud (1999) to be more abundant in a maize field with deep tillage than in field with no or only superficial tillage. In the PRE practice, only *S. assimilis* was occasionally more abundant than in the other practices. This species, which occurs in small water bodies or in other wet habitats (Bretfeld, 1999), may have thrived better in PRE, because there was a greater number of puddles than in the other practices, resulting from the higher soil density. The strong seasonal fluctuations of abundance are one of the characteristics of the arthropod communities of Mediterranean area, where fauna is highly dependent on spring and autumn precipitation.

In order to obtain a mechanistic understanding of the dynamics of the collembolan communities, we have classified the common species using the life-history tactics of Siepel (1994) which are based on 12 life-history traits: *S. assimilis*, *S. viridis*, *S. pumilis and S. elegans* were ascribed to the tactic V, *M. krausbaueri* to the tactic X, and *C. denticulata*, *C. thermophilus*, *E. lanuginosa and L. cyaneus* to the tactic XI. The FLOR practice favoured a tactic of synchronization (diapause in *S. pumilis* and *S. elegans*), reproduction tactics were well represented in POST (thelytoky for *M. krausbaueri* or sexual reproduction for *C. thermophilus*), and TIL favoured only a sexual reproduction tactic (*C. denticulata* and *L. cyaneus)*. Siepel (1995) found more synchronization tactics in a non-fertilized grassland than in a fertilized one. The results from this study are in agreement, as FLOR, the least disturbed treatment, favoured a synchronization tactic. Thelytoky may better be represented in a stable habitat; therefore, as a habitat is increasingly disturbed, thelytoky declines, and is replaced by sexual reproduction (Siepel, 1995). As a highest proportion of thelytoky was found in the POST than in TIL, this suggests that the environment is more stable in POST.

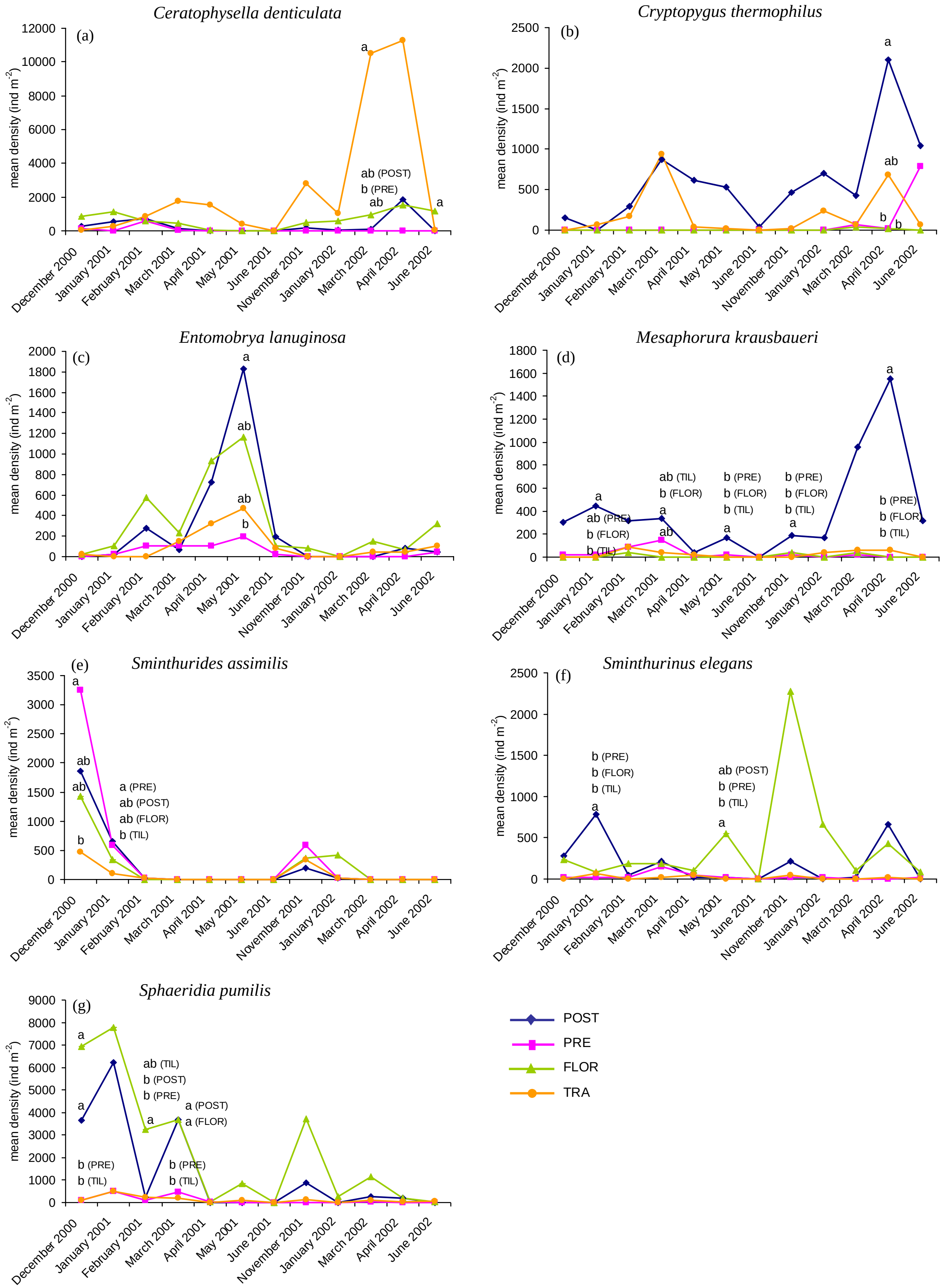


Figure 2. Changes in mean density (ind m^{-2}) of (a) *C. denticulata*, (b) *C. thermophilus*, (c) *E. lanuginosa*, (d) *M. krausbaueri*, (e) *S. assimilis*, (f) *S. elegans* and (g) *S. pumilis*. Significant differences between treatments are marked by different letters. Vertical bars are standard errors (one-way ANOVA, Tukey's HSD test, $P<0.05$, $n=72$).

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References

Alvarez, T., Frampton, G.K., Goulson, D., 2001. Epigeic Collembola in winter wheat under organic, integrated and conventional farm management regimes. Agric. Ecosyst. Environ. 83, 95–110.

Bretfeld, G., 1999. Synopses on Paleartic Collembola, vol. 2: Symphypleona. In: Dunger, W. (Ed.), Staatliches Museum für Naturkunde Görlitz.

Cortet, J., Balaguer-Poinsot, N., 2000. Impact de produits phytopharmaceutiques sur les microarthropodes du sol en culture de maïs irrigué: approche fonctionnelle par la méthode des sacs de litière. Can. J. Soil Sci. 80, 237–249.

Dekkers, Th.B.M., van Der Werff, P.A., van Amelsvoort, P.A.M., 1994. Soil Collembola and Acari related to farming systems and crop rotations in organic farming. Acta Zool. Fenn. 195, 28–31.

Favretto, M.R., Paoletti, M.G., Caporali, F., Nannipieri, P., Onnis, A., Tomei, P.E., 1992. Invertebrates and nutrients in a Mediterranean vineyard mulched with subterranean clover (*Trifolium subteraneum* L). Biol. Fertil. Soils 14, 151–158.

Garrett, C.J., Crossley Jr, D.A., Coleman, D.C., Hendrix, P.F., Kisselle, K.W., Potter, R.L., 2001. Impact of the rhizosphere on soil microarthropods in agroecosystems on the Georgia piedmont. Appl. Soil Ecol. 16, 141–148.

Loring, S.J., Snider, R.J., Robertson, L.S., 1981. The effects of three tillage practices on Collembola and Acarina populations. Pedobiologia 22, 185–193.

Mallow, D., Snider, R.J., Robertson, L.S., 1985. Effects of different management practices on Collembola and Acarina in corn production systems. II. The effects of moldboard plowing and atrazine. Pedobiologia 28, 115–131.

Moore, J.C., Snider, R.J., Robertson, L.S., 1984. Effects of different management practices on Collembola and Acarina in corn production systems. I. The effects of no tillage and atrazine. Pedobiologia 26, 143–152.

Reinecke, A.J., Helling, B., Louw, K., Fourie, J., Reinecke, S.A., 2002. The impact of different herbicides and cover crops on soil biological activity in vineyards in the Western Cape, South Africa. Pedobiologia 46, 475–484.

Renaud, A., 1999. Les microarthropodes du sol, bioindicateurs des sols agricoles en zone de grande culture. Rapport du DEA Biosciences de l'Environnement, Santé et Chimie, Faculté des Sciences et Techniques de Saint-Jérôme. Université d'Aix-Marseille III, Marseille, France.

Siepel, H., 1994. Life-history tactics of soil microarthropods. Biol. Fertil. Soils 18, 263–278.

Siepel, H., 1995. Applications of microarthropod life-history tactics in nature management and ecotoxicology. Biol. Fertil. Soils 19, 75–83.

Statsoft, 1998. Statistica for Windows Version 5.1. Tulsa, OK, USA.

Sturm Jr., M., Sturm, M., Eisenbeis, G., 2002. Recovery of the biological activity in a vineyard soil after landscape redesign: a three-year study using the bait-lamina method. Vitis 41, 43–45.

Tullgren, A., 1918. Ein sehr einfacher Ausleseapparat für terricole Tierformen. Z. Angew. Entomol. 4, 149–150.

Wiegert, R.G., 1974. Litter-bags study of microarthropod populations in three south Carolina old fields. Ecology 55, 94–102.