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Biodiversity of Collembola in tropical agricultural environments of Espírito Santo, Brazil

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Abstract

Despite the environmental importance of Collembola, basic information on the occurrence and ecology of these soil microarthropods is lacking, especially in Neotropical and agricultural environments. To address such gaps in information this research was conducted with objectives to determine what Collembola species inhabit agricultural soils of Espírito Santo, Brazil; obtain a record of the seasonal abundance of Collembola in this area; and to investigate effects of alternative agricultural practices on Collembola in this tropical environment. Research field sites are located in Domingos Martins municipality, Espírito Santo (20°23′S, 41°03′W) and consist of three sites: (A) fertilizer site, with two fertilizer treatments, organic fertilizer and inorganic fertilizer; (B) tillage site, with two tillage treatments, no tillage and conventional tillage; and (C) mulch site, with two mulch treatments, mulch and no mulch. Experimental plots have received similar treatments since the sites were established (1991, 1992) and a variety of crops are grown on the sites annually. From December 1999 to November 2000, soil core samples (4.8 cm diameter) were taken randomly from the surface 10 cm of each plot every 28–71 days. Tullgren funnels were used to extract Collembola from the soil samples and the Collembola collected were identified and quantified. A total of 9650 collembolan specimens was collected from 88 samples taken at approximately 2 month intervals, averaging 60,600 Collembola per meter square, including 38 species and three probable new species. Averaged across sites and treatments, total collembolan density was greater in September than in December. Total collembolan densities were greater with no tillage versus conventional tillage and with mulch versus no mulch.

Keywords: Collembola; Tropical biodiversity; Agroecosystems; Brazil

1. Introduction

Collembola are common and abundant in soils throughout the world and by feeding on soil microorganisms and dead organic matter these soil microarthropods have significant influences on soil microbial ecology, nutrient cycling, and soil fertility (Hopkin, 1997; Larink, 1997). However, despite their environmental importance, basic information on the occurrence and ecology of Collembola is lacking (Andre et al., 1994). The Neotropical collembolan fauna is probably the most diverse but least known in the world (Mari Mutt and Bellinger, 1990) and prior to preliminary results of this study (Culik et al., 2000) only eleven species of Collembola were known from Espírito Santo, Brazil, although this area contains some of the most diverse tropical forests in the world (Mori, 1989). Information on the biology of soil microarthropods in agroecosystems is also limited (Crossley et al., 1992) but necessary for development

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of sustainable agricultural systems (Pankhurst et al., 1994).

A basic first step in understanding the ecology of Collembola in tropical, agricultural, and other environments is knowledge of what species occur in such environments (Stork and Eggleton, 1992). And, because soil faunal abundance typically varies seasonally and annually, seasonal and multiannual data on the abundance of these organisms is also needed to understand their role in ecosystems (Petersen and Luxton, 1982).

Alternative agricultural practices such as the use of compost as an organic fertilizer, no tillage, and mulch application are potentially economical methods to support sustainable crop production in Espírito Santo, and the effects of these practices on soil physical, chemical, and biological properties are being investigated as part of ongoing research initiated in 1990 (Souza, 1998). Regarding the effects of such alternative agricultural practices on Collembola, a variety of studies indicate that collembolan densities are greater in soils fertilized with manure or combinations of manure plus inorganic fertilizer compared to soils fertilized with inorganic fertilizer alone (Raw, 1967; Artemjeva and Gatilova, 1975; Marshall, 1977; Andrén and Lagerlof, 1980, 1983; Mitra, 1993). However, no studies have been done to determine if compost has a similar positive effect on collembolan populations in tropical agricultural soils. Under temperate agricultural conditions in which single crops are typically grown annually, tillage initially causes sharp decreases in collembolan densities and is associated with large fluctuations in collembolan abundance (Sheals, 1956; Loring et al., 1981), and individual Collembola species differ in response to the type of tillage used (Dittmer and Schrader, 2000) with tillage tending to reduce populations of surface dwelling Collembola compared to no or reduced tillage (Edwards and Lofty, 1975; Winter et al., 1990). Mitra (1993) indicated that extremely low collembolan densities found in agricultural soils in India compared to temperate areas were due in part to year round crop production, including tillage, under tropical conditions. But, there does not appear to be any experimental data regarding effects of no tillage versus conventional tillage on Collembola in tropical environments. As with no tillage, mulching is likely to influence collembolan populations through creation or maintenance of an insulating surface layer of dead organic material or plant debris (litter). Results of Cabral (Cabral, R.S., 1994. Avaliação qualitativa e quantitativa de Collembola (Insecta), em ecossistemas de *Coffea arabica* L. Dissertação (Mestrado). Univ. Fed. de Viçosa.) indicate that collembolan populations may be more stable in perennial agricultural environments that have a litter layer but it is unclear if such stability would also occur with mulch application (or no tillage) in tropical, seasonal, year round crop production environments. Soil microarthropod densities tend to be greater on mulched versus unmulched sites (Badejo et al., 1995) but specific effects of mulch on individual Collembola species have not been reported.

The goal of this research, was to address these gaps in information on Collembola, to increase basic knowledge of the collembolan fauna of Espírito Santo, and to thus add to knowledge of Neotropical Collembola and increase understanding of the biodiversity of Collembola in tropical and agricultural environments. Specific objectives of this research were to determine what Collembola species inhabit agricultural soils of Espírito Santo, obtain a record of the seasonal abundance of Collembola in this area, and to investigate effects of alternative agricultural practices (organic versus inorganic fertilizer application, tillage versus no tillage, and mulch versus no mulch application) on Collembola communities and species in this tropical environment.

2. Materials and methods

Experimental field sites for this research are located at the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (INCAPER) Central Mountain Center (CRDR-CS), Domingos Martins municipality, Espírito Santo (20°23′S, 41°03′W), and consist of three sites designated: (A) fertilizer site, the site contains two blocks with plots (100 m^2) subjected to two soil fertilizer treatments, organic fertilizer (15,000 kg dry compost/ha per crop) and inorganic fertilizer (inorganic fertilizer amounts based on requirements for each crop); (B) tillage site, the site has two blocks with plots (165 m^2) subjected to two different tillage treatments, no tillage (direct planting) and tillage (conventional plowing and disking prior to planting); and (C) mulch site, the site contains two blocks with plots (150 m^2) subjected to two different mulch treatments, mulch (rice hull or chopped grass applied to a depth of

Table 1
Soil characteristics of field sites A–C managed with contrasting agricultural practices

Characteristics	Value of soil characteristic by site and treatment					
	Site A		Site B		Site C	
	Organic fertilizer	Inorganic fertilizer	No tillage	With tillage	With mulch	No mulch
Soil type[a]	Latossolo	Latossolo	Latossolo	Latossolo	Aluvial	Aluvial
Texture[b]	–	–	Clay	Clay	Sandy clay loam	Sandy clay
Silt:clay (%)[b]	–	–	19:46	17:49	19:32	17:36
pH[c]	7.2	6.3	7.0	7.1	7.0	7.0
Organic matter (%)[c]	3.5	1.9	3.0	2.7	4.7	3.3

[a] Latossolo and Aluvial classes correspond primarily to Oxisol and Entisol, respectively of Soil Taxonomy, Soil Survey Staff, 1975 (Camargo et al., 1986).
[b] Determined in 2001.
[c] Determined in 2000.

2–3 cm at planting) and no mulch applied. Soil characteristics of the study sites are summarized in Table 1. Crops grown on sites were cabbage, carrots, corn, oats, and potatoes, with at least two crops grown on each site during the year of this study. For each treatment, the same plots have received similar treatments annually since the sites were established in 1992 (site A) and 1991 (sites B and C). Field sites were irrigated as needed based on crop requirements. The research location has hot, rainy summer and cool, dry winter climatic conditions. During the study period (December 1999–November 2000) temperature and precipitation levels at the research location were in the range typical for the area with monthly temperatures varying from an average of 21.4 °C in February to 13.3 °C in July 2000 and total monthly precipitation ranging from 222 mm in November to 9 mm in July 2000.

Two soil core samples (4.8 cm diameter) were taken randomly (between plants in rows if crops were present) from the surface 10 cm of each plot at intervals of 28–71 days from December 1999 to November 2000. Collembola were extracted from the soil cores using Tullgren funnels (18 and 4 cm diameter top and bottom, respectively; 30 cm long) with 25 W light bulbs mounted in 24 cm diameter reflectors used as heat sources. Soil cores were placed on wire screens (2 mm mesh) in the funnels approximately 15 cm below the bulbs. Collection jars (200 ml) with approximately 50 ml 70% ethanol plus 5% glycerin were attached below the funnels and the extraction period was 6 days. Specimens collected were identified as far as possible to species level and quantified to estimate the collembolan densities of the sites. Because Collembola were much more numerous in samples than anticipated, identification of specimens collected was not completed for all samples and this report presents results from a total of 88 samples collected at intervals of approximately 2 months (56–71 days), one sample per plot on all sample dates except two samples per plot on 21 December 99 (all sites) and 15 February 2000, site A.

Characteristics of the collembolan communities (density, species richness, diversity, equitability, and dominant species) were determined to evaluate the effects of treatments on collembolan communities. Diversity was measured with the Shannon-Wiener index (H'). Data was transformed by $\ln(x + 1)$ and t-tests applied to the transformed data to test for treatment effects on the density of total Collembola and specific Collembola taxa, and to test for differences in total Collembola density for the months in which the lowest and highest number of Collembola per sample were collected (December versus September). One-tailed t-tests were used to test hypotheses that the density of total Collembola was greater with alternative agricultural practices; organic fertilizer, no tillage, mulch versus inorganic fertilizer, conventional tillage, no mulch, respectively. Otherwise, two-tailed t-tests were used.

3. Results

A total of 9650 Collembola specimens was collected, averaging across sites and treatments 110 Collembola per sample and 60,600 Collembola per

Table 2
Mean density (number per meter square) of Collembola for field sites A–C managed with contrasting agricultural practices, December 1999–November 2000 (site A, 16 samples/treatment; sites B and C, 14 samples/treatment)

Taxa	Total number of each Collembola taxa collected by site and treatment					
	Site A		Site B		Site C	
	Organic fertilizer	Inorganic fertilizer	No tillage	With tillage	With mulch	No mulch
Ceratophysella boletivora	12676	13816	158	513	8645	2408
Hypogastrura manubrialis	0	0	0	0	1579	39
Xenylla welchi	0	0	513	118	79	0
Xenylla sp. 2	0	0	39	0	0	0
Brachystomella sp. 1 (sp. nov.)	2038	2349	237	79	592	0
Friesea sp. 1	104	0	0	0	39	39
Vitronura giselae	898	518	316	197	868	237
Unidentified Hypogastruridae	35	0	39	0	39	0
Thalassaphorura encarpata	4041	3385	4026	1026	6316	3908
Mesaphorura yosiii	1071	656	39	39	2605	513
Mesaphorura silvicola	0	138	39	0	0	39
Mesaphorura simoni	104	69	0	0	0	0
Folsomides centralis	16233	5284	22618	11802	60196	39749
Proisotoma minuta	1934	173	434	79	316	750
Proisotoma tenella	35	0	513	79	118	0
Folsomides parvulus	69	0	0	0	0	0
Ballistura fitchi	69	0	3395	118	0	0
Cryptopygus thermophilus	0	0	474	829	1263	671
Desoria trispinata	2245	587	947	79	513	316
Isotomiella symmetrimucronata	1071	760	987	474	4934	237[a]
Isotomodes ccoccatirensis 1 sp. aff. pseudoproductus	449	311	1697	316[a]	158	0
Isotomurus bimus	725	276	1658	1697	1026	1816
Folsomia wellingdae	104	69	39	118	39	197
Folsomia amazonae	0	0	0	0	39	79
Folsomina onychiurina	0	311	0	0	39	39
Unidentified Isotomidae	242	69	276	158	513	118
Heteromurus sp. 1	35	69	39	39	0	0
Entomobrya sp. 1	1036	553	158	158	237	79
Lepidocrytus nr. mutabilis	0	0	0	0	118	39
Pseudosinella nr. *biunguiculata*	16371	9705	5763	1618[a]	2092	2921
Pseudosinella sp. 2	6132	6908	10302	12158	9987	1224[a]
Unidentified Entomobyidae	35	35	237	276	355	158
Cyphoderus sp. 1	276	449	118	0	39	0
Trogolaphysa sp. 1	0	0	79	79	0	0
Campylothorax sp. 1	0	0	39	79	39	0
Neelus tristani	414	104	789	750	789	592
Arrhopalites sp. 1 (sp. nov.)	0	104	0	39	0	0
Sminthurinus sp. (juvenile)	35	0	0	0	0	0
Sminthurinus sp. 1	0	0	0	0	39	276
Sminthurinus sp. 2	0	0	79	39	0	0
Bourletiella sp. 1	0	35	0	0	0	0
Unidentified Sminthuridae	0	0	0	39	39	39
Collembola, total	68525	46731	56052	32999[a]	103656	56486[a]

[a] Following density indicates that the collembolan density is significantly different from that of the contrasting treatment ($P < 0.05$; one-tailed t-test for total density; two-tailed t-test for individual taxa). Otherwise, no significant differences in collembolan densities for contrasting treatments were found ($P > 0.05$; one-tailed t-test for total density; two-tailed t-test for individual taxa).

meter square. In addition to being abundant, a diverse variety of Collembola was found, including a total of 38 species, with at least 28 species present on each site (Table 2). Among the species found were three probable new species. Averaged across sites and treatments, Collembola density was greater in September than in December, 80,500 Collembola per meter square versus 38,800 Collembola per meter square, respectively ($P < 0.05$). However, the time of peak Collembola density also varied depending on site and management/treatment factors (Fig. 1) as well as species (unpublished data).

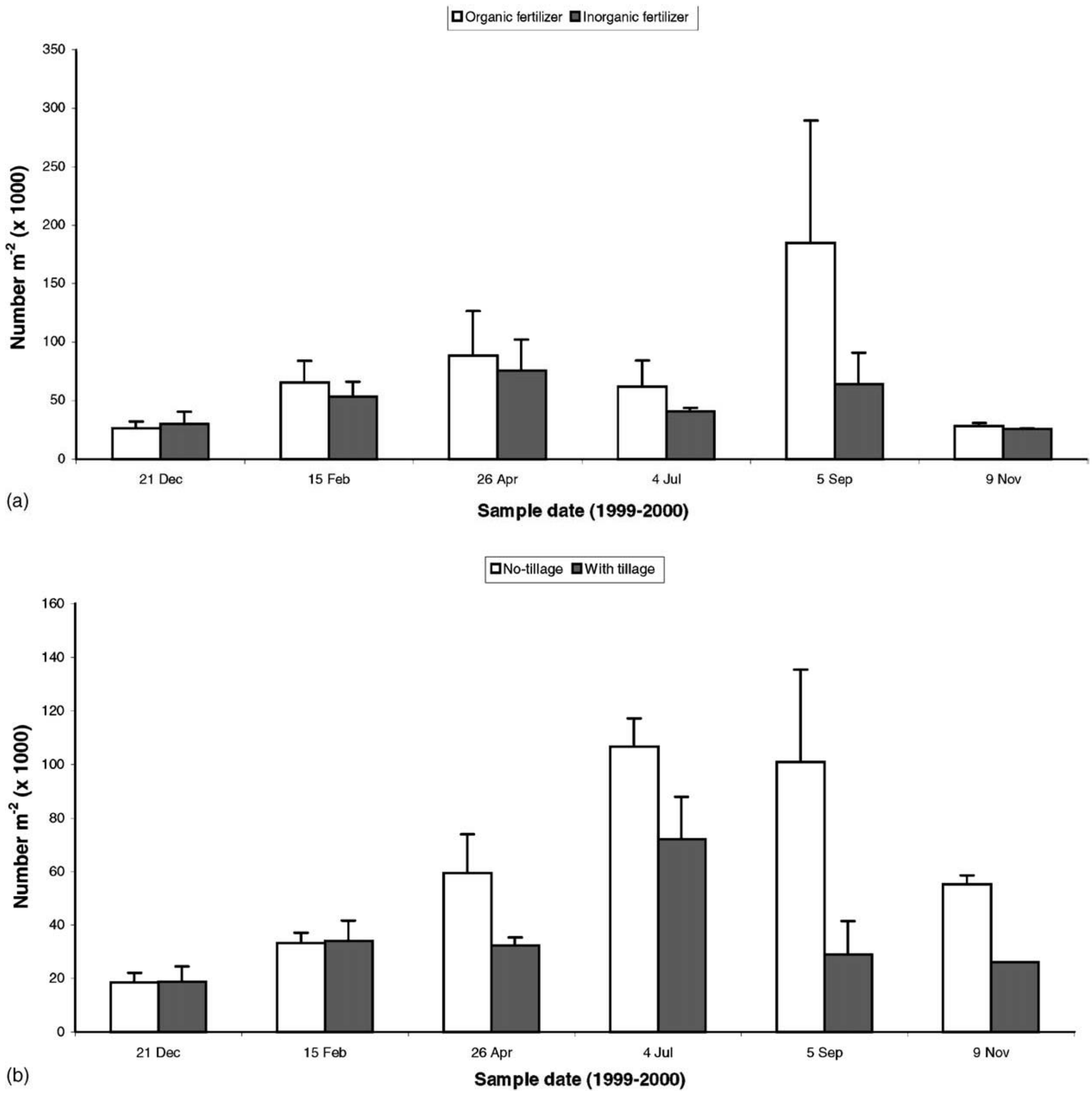

Fig. 1. The mean densities of Collembola on the six sampling dates in the two treatments of: (a) site A; (b) site B; (c) site C; and (d) sites A–C combined. The vertical bars show the standard error of the mean.

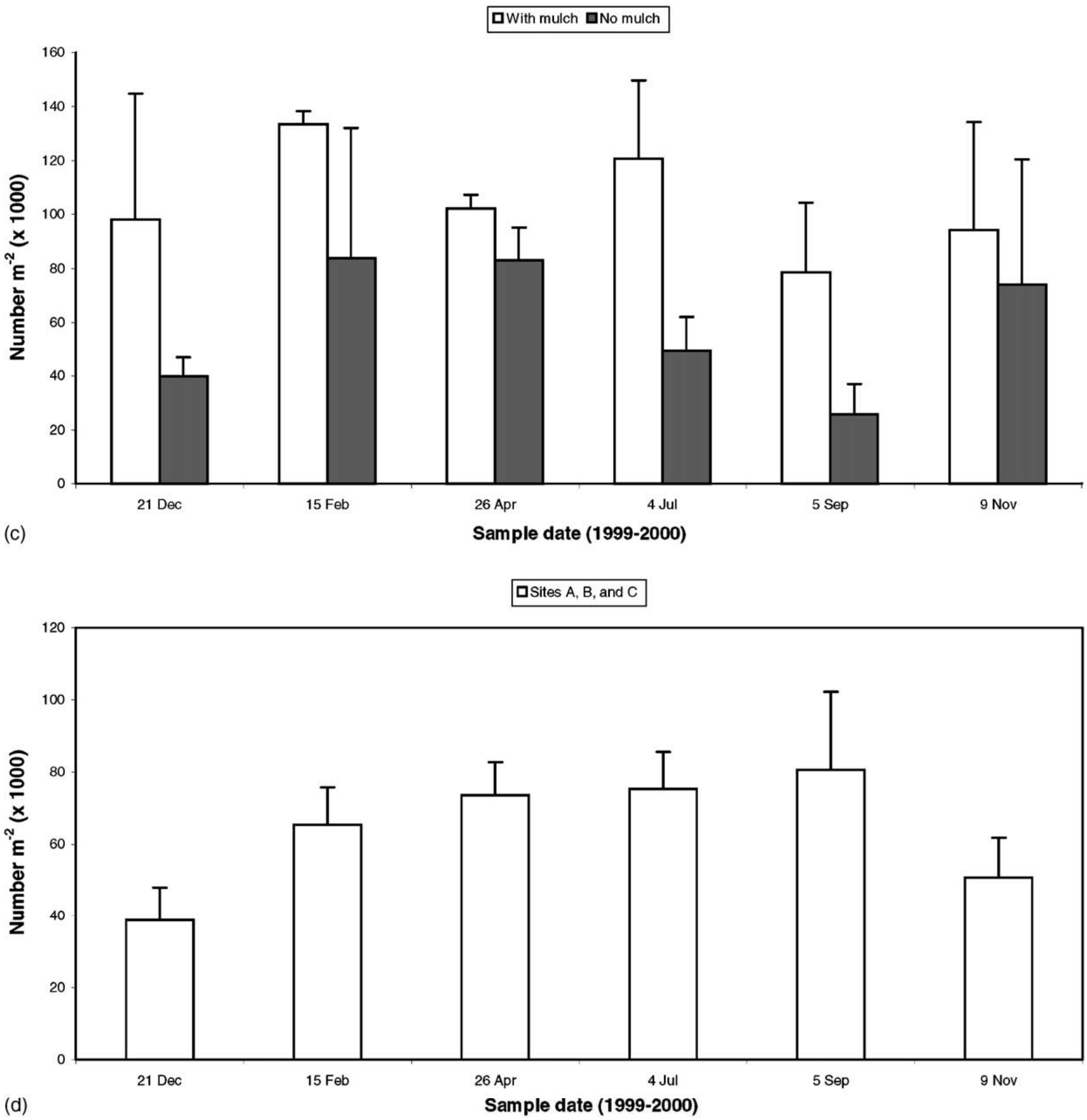

Fig. 1 (*Continued*).

Type of fertilizer did not affect mean density of total Collembola ($P > 0.05$) but total collembolan density was significantly greater with the no tillage versus tillage and with mulch versus no mulch application ($P < 0.05$), Table 3. There was also little difference in species richness, diversity, and evenness between organic and inorganic fertilizer (and no tillage and tillage) treatments. However, species richness, diversity, and evenness tended to be greater with mulch versus no mulch application. Eight Collembola species were dominant (consisting of 5% or more of the individuals found in each treatment)

Table 3
Diversity and related characteristics of Collembola communities for field sites A–C managed with contrasting agricultural practices

Characteristics	Value of Collembola community characteristic by site and treatment					
	Site A		Site B		Site C	
	Organic fertilizer	Inorganic fertilizer	No tillage	With tillage	With tillage	No tillage
Total density						
Mean (10^3 m^{-2})	68.5	46.7	56.1[a]	33.0	103.7[a]	56.5
Number of samples	16	16	14	14	14	14
Richness, *s*	24	23	27	25	27	22
Diversity, H'	2.14	2.05	2.00	1.74	1.62	1.28
Evenness,						
E, $H'/\ln s$	0.67	0.65	0.61	0.54	0.49	0.41
Dominant species[b]	Cbol	Cbol			Cbol	
		Bra1				
	Tenc	Tenc	Tenc		Tenc	Tenc
	Fcen	Fcen	Fcen	Fcen	Fcen	Fcen
			Bfit			
				Ibim		
	Pbiu	Pbiu	Pbiu[a]			Pbiu
	Pse2	Pse2	Pse2	Pse2	Pse2[a]	
Dominant percent[c]	81	89	81	78	82	82

[a] Following density and dominant species indicates that the collembolan density is significantly greater ($P < 0.05$) than in the contrasting treatment (one-tailed *t*-test for total density; two-tailed *t*-test for dominant species).

[b] Dominant species are those making up 5% or more of the total Collembola found for each treatment: Cbol, *Ceratophysella boletivora*; Bra1, *Brachystomella* sp. 1; Tenc, *Thalassaphorura encarpata*; Fcen, *Folsomides centralis*; Bfit, *Ballistura fitchi*; Ibim, *Isotomurus bimus*; Pbiu, *Pseudosinella* nr. *biunguiculata*; Pse2, *Pseudosinella* sp. 2.

[c] Dominant species percentage of the total number of Collembola collected in treatment.

and four species, *Thalassaphorura encarpata*, *Folsomides centralis*, *Pseudosinella* nr. *biunguiculata*, and *Pseudosinella* sp. 2, were dominant in all three sites (Table 3). Together, the dominant species accounted for approximately 80–90% of the Collembola collected within each treatment. Of the dominant species, *P.* nr. *biunguiculata* density was significantly greater with no tillage versus tillage; and *Pseudosinella* sp. 2 density was greater with mulch versus no mulch application ($P < 0.05$), Table 3.

4. Discussion

The overall mean Collembola density observed in this study (60,600 m^{-2}) is much higher than that commonly found in studies of fauna of tropical and agricultural soils. A variety of researchers have noted that the abundance of soil fauna is lower in tropical soils than in comparable temperate soils. Salt (1952) estimated a density of ∼38,000 soil arthropods per meter square in African sites and concluded that soil arthropod abundance of tropical pasture is about half that of temperate pasture. Madge (1965) emphasized that the total soil fauna found in a tropical forest studied (Collembola density ∼13,000 m^{-2}) was low compared with some temperate regions. Heneghan et al. (1998) reported that lower abundances of soil microarthropods at tropical sites (Collembola density <4000 m^{-2}) confirmed observations of many researchers and Petersen and Luxton (1982) indicated that, in general, total soil fauna biomass and Collembola densities are lower in tropical versus temperate regions. An exception to studies reporting low tropical soil fauna densities is that of Badejo et al. (1998) who found Collembola densities of 72,000 and 82,000 m^{-2} in grass and forest soils, respectively, and up to 271,000–556,000 Collembola per meter square in soils of agroforestry trees in Nigeria. This study provides additional evidence that high soil fauna densities may also occur in tropical soils.

Relatively low Collembola densities ($<20{,}000\,m^{-2}$) are also commonly found in agricultural soils in temperate (Artemjeva and Gatilova, 1975; Andrén and Lagerlof, 1980; Winter et al., 1990; Dittmer and Schrader, 2000) and tropical environments (Mitra, 1993; Badejo and Van Straallen, 1993; Badejo et al., 1995). However, as with tropical soils, high Collembola densities ($>50{,}000\,m^{-2}$) have also been found in some agricultural soils, at least in temperate environments (Andrén and Lagerlof, 1983; Heisler and Kaiser, 1995; Axelsen and Kristensen, 2000). This study appears to be among the first to demonstrate that relatively high Collembola densities also occur in tropical agricultural soils.

Of the 38 Collembola species found, half (19) are widely distributed (known also from North America, Europe, or Asia). The remaining 19 species apparently are less widely distributed, including three known only from South America, and at least three others previously undescribed. Of the eight dominant species, five have widespread distributions (*C. boletivora*, *T. encarpata*, *F. centralis*, *Ballistura fitchi*, *Isotomurus bimus*) and the other three are apparently Neotropical (*Brachystomella* sp. 1, *P.* nr. *biunguiculata*, *Pseudosinella* sp. 2). On each site, 28–29 species were found, which is remarkably similar to the species richness of 25–30 found in agricultural soils in the US and Europe (Artemjeva and Gatilova, 1975; Loring et al., 1981; Axelsen and Kristensen, 2000; Dittmer and Schrader, 2000). As in this study, seven genera of Collembola have included dominant species in agricultural soils in Europe (Artemjeva and Gatilova, 1975; Heisler and Kaiser, 1995; Axelsen and Kristensen, 2000; Dittmer and Schrader, 2000) but only two genera dominant in this study (*Ceratophysella* and *Isotomurus*) were also listed among the dominant genera in the European studies.

The time of peak Collembola density appeared to vary depending on the site and treatment but Collembola density was greater in September than in December and overall density tended to be greatest in winter and lowest in summer. This result is somewhat surprising since collembolan abundance is commonly positively related to moisture (Badejo and Van Straallen, 1993) and at this study location greater precipitation occurs during summer months (total precipitation at the study location was 525.6 mm December 1999–February 2000 versus 98.3 mm June–August 2000). However, because study sites were irrigated, moisture probably was not a limiting factor. Instead, high temperatures or related climatic conditions may have limited populations in summer months. This is consistent with results of Badejo and Van Straallen (1993) who found a negative relationship between Collembola abundance and temperature under tropical climatic conditions (mean monthly temperatures at this study location ranged from 20.3 to 21.4 °C December 1999–February 2000 versus 13.3–13.8 °C June–August 2000).

Although, the difference was not statistically significant, total Collembola density tended to be greater in soils fertilized with organic fertilizer versus inorganic fertilizer which is consistent with a variety of studies indicating that collembolan densities are greater in soils fertilized with manure or combinations of manure plus inorganic fertilizer compared to soils fertilized with inorganic fertilizer alone (Raw, 1967; Artemjeva and Gatilova, 1975; Marshall, 1977; Andrén and Lagerlof, 1980, 1983; Mitra, 1993). Results of this study are also in agreement with previous studies of the effects of tillage on Collembola. Collembola densities were greater with no tillage versus conventional tillage, at least in the top 10 cm of soil, as was also found by Winter et al. (1990) and different Collembola species were affected differently by tillage treatment as observed by Dittmer and Schrader (2000). Edwards and Lofty (1975) reported that Entomobryidae were most negatively influenced by tillage compared to no tillage, and in this study the abundance of the entomobryid *Pseudosinella* nr. *biunguiculata* was significantly lower with tillage versus no tillage. However, in the present study, total Collembola densities appeared to be highest in some of the other experimental areas that were subjected to tillage (organic fertilizer and mulch treatments of sites A and C, respectively) compared to densities found with no tillage, suggesting that the effects of tillage on Collembola are variable and dependent on other factors. Results of this study are also consistent with those of Badejo et al. (1995) indicating that mulch has a positive effect on collembolan abundance. Species richness, diversity, and evenness tended to be greater with mulch versus no mulch application indicating that the positive effect of mulch on collembolan abundance is due to positive effects on many of the species present rather than on a few dominant species.

Pseudosinella sp. 2 was one of the species that clearly benefited from mulch application in this study.

In conclusion, these results confirm that a diverse variety of Collembola species inhabits soils in Espírito Santo. This study also provides additional evidence of exceptions to generalizations that soil microarthropod densities are low in tropical and agricultural environments compared to temperate and non-agricultural environments. And, these initial data on the species present and effects of seasonal climatic conditions and agricultural practices on Collembola in this tropical environment provide a basis for further research on Collembola in this region.

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