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Rotation/Succession Systems Affects Springtails (Hexapoda: Collembola) Abundance in Cash Crops Under No Tillage Cultivation

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Abstract

Acknowledging the bio indicator importance of springtails (Hexapoda: Collembola) for soil quality, this study aimed to determine the abundance of these arthropods in different systems of rotation/succession with commercial and cover crops, while also verifying the agricultural factor associated to these arthropods' population. In the Instituto de Desenvolvimento Rural do Paraná (IAPAR-EMATER), during six years, areas with differing crops in rotation/succession adopting the no-tillage system were studied. For each system, chemical analyses of the soil were conducted and the number of captured springtails in pitfall traps was counted. The phytosanitary products applied during the evaluations and the quantity of vegetal cover remaining after harvest were considered as well. No difference was found between the rotation/succession systems in relation to chemical soil attributes, however the largest number of springtails was found in crop covers from corn, *Brachiaria* sp., and canola. These crop covers, including wheat, resulted in the highest straw dry mass. When removing the system in which the predecessor crop had the highest quantities of fungicide application, a positive correlation ($r = 0.63$; $p < 0.01$) was found, between springtail abundance and highest amount of straw after the harvest. If no fungicide applications occur, the crops with the largest amount of vegetal cover favor springtail populations.

Keywords: soil quality, bio indicators, poduromorpha, straw, mancozebe

1. Introduction

The no-tillage system is largely adopted in Brazil, currently considered the main grain crop management system in the country. The wide acceptance is due primarily to the reduction in loss of soil caused by erosion and the benefits towards chemical, physical, and biological properties of the soil (Bolliger et al., 2006). The no-tillage system supports a gradual improvement of soil quality due to the increase in organic matter content and biological activities (Duda et al., 2003; Gatiboni et al., 2009).

Leguminous plants are commonly used for soil cover, but other plant families are also used to maintain adequate cover (Menezes et al., 2004). In rotation or succession systems plant diversity is desired, which result in large straw residue production, low decomposition rate, nutrient cycling promotion and biological nitrogen fixation (Leal et al., 2005).

The presence of vegetal cover and no-tillage systems favor the edaphic fauna, which result in a greater diversity of organisms when compared to conventionally cultivated areas (Alves et al., 2006; Baretta et al., 2006; Gatiboni et al., 2009). This is closely related to the quantity and quality of organic residues available to organisms that inhabit the soil, directly influencing their abundance (Warren & Zou, 2002; Antoniolli et al., 2006).

Studies assessing different soil management systems' effects on the edaphic fauna, demonstrate that the most abundant arthropod orders are Acari, Collembola, Coleoptera, Hymenoptera and Araneae (Silva et al., 2013; Silva et al., 2015; Santos et al., 2016). Organisms capable of determining the quality or level of soil degradation are considered as bioindicators (Wink et al., 2005).

Springtails (Hexapoda: Collembola) are small arthropods, wingless and part of the mesofauna and are among the most abundant invertebrates in the soil (Alves & Cardoso, 2016; Culik & Zeppelini, 2003). They are considered one of the main groups of organisms used as bioindicators (Rusek, 1998; Bellinger et al., 2020), as they partake in the physico-chemical processes of the ecosystem, fragmentation, decomposition, and mineralization of soil organic matter, and are very important in maintaining soil quality and consequent nutrient cycling (Jänsch, Amorim, & Römbke, 2005).

Springtails have little resistance to dehydration (Crouau, Chenon, & Gisclard, 1999; Eisenbeis, 1983; Hojer, Bayley, Damgaard, & Holmstrup, 2001) and are highly dependent on soil moisture to survive (Peijnenburg et al., 2012). Drought conditions, even in uncontaminated soils, can impair their metabolic activities and reproductive performance, dwindling their population (González-Alcaraz & Van Gestel, 2016; Holmstrup et al., 2010).

Due to the sensitivity to changes in the environmental conditions in soil management, crop cultivation and mainly to soil degradation, springtails could be used as bioindicators of changes caused by incorrect soil management (Damé et al., 1996; Bedano et al., 2016).

Considering that the populations of springtails are bioindicators of soil quality, the present study aimed to determine the abundance of springtails in different rotation/succession systems, including cash and cover crops, adopting the no-tillage system, as well as, the agricultural factors associated with this arthropods' population.

2. Material and Methods

2.1 Characterization of the Experimental Area

The experiment was carried out at the Instituto de Desenvolvimento Rural do Paraná (IAPAR-EMATER) (IDR-Paraná) in Londrina, PR (coordinates 23°22′ S; 51°10′ W; 585 m a.s.l.). According to Köppen's classification, the region's climate is humid subtropical with hot summers (Cfa), with an average annual temperature of 21.1 °C and an average annual precipitation of 1639 mm (IDR-PR, 2020). The soil is classified as Rhodic Ferralsol with a very clayey texture (Santos et al., 2018).

The experiment stated in 2014, and during six years, different crops following a rotation and succession of commercial and cover plants were cultivated, always following a no-tillage system. Six different rotation/succession systems (treatments) were performed, including the most common production system in the northern region of Paraná, soybean followed by corn (Table 1). The cash and cover crops were sown in plots of 25 m^2 (5 × 5 m), with four replicates, following a random block experimental design.

Table 1. Plants used in different rotation/succession systems (treatments) during six agricultural harvests. Experimental area from the Instituto de Desenvolvimento Rural do Paraná (IAPAR-EMATER) in Londrina, State of Paraná

Harvests	Season	Treatments (rotation/succession systems)					
		T1	T2	T3	T4	T5	T6
2014/2015	Winter	Corn	White oats	Rye + Black oats	Canola	Buckwheat + Turnip	Wheat
	Summer	Soy	Soy	Soy	Corn	Corn	Corn + *Braquiaria*
2015/2016	Winter	Corn	Rye	Turnip + Black oats	*Crambe*	Common bean	Canola
	Summer	Soy	Corn	Corn	Corn	Soy	Corn + *Braquiaria*
2016/2017	Winter	Corn	Wheat	*Braquiaria*	Safflower	Buckwheat + Black oats	Common bean
	Summer	Soy	Soy	Soy	Soy	Soy	Soy
2017/2018	Winter	Corn	White oats	Rye + Black oats	Canola	Buckwheat + Turnip	Wheat
	Summer	Soy	Soy	Soy	Corn	Corn	Corn + *Braquiaria*
2018/2019	Winter	Corn	Triticale	Turnip + Black oats	*Crambe*	Common bean	Canola
	Summer	Soy	Corn	Corn	Corn	Soy	Corn + *Braquiaria*
2019/2020	Winter	Corn	Wheat	*Braquiaria*	Canola	Buckwheat + Black oats	Common bean
	Summer	Soy	Soy	Soy	Soy	Soy	Soy

Note. White oats (*Avena sativa*), Black oats (*Avena strigosa*), Brachiaria (*Brachiaria ruziziensis*), Canola (*Brassica napus*), Safflower (*Carthamus tinctorius*), Rye (*Secale cereale*), Crambe (*Crambe abyssinica*), Common bean (*Phaseolus vulgaris*), Corn (*Zea mays*), Turnip (*Raphanus sativus*), Soy (*Glycine max*), Wheat (*Triticum aestivum*), Buckwheat (*Fagopyrum esculentum*), Triticosecale (*Triticosecale*).

2.2 Crop Managements Conducted During 2019 and 2020

The crop drying before the sowing of every vegetable in the different rotation/succession system was carried out with the following herbicides: Glyphosate®, Aurora® and Assist®. In every crop, except *Brachiaria* sp., seed treatment was carried out with Vitavax® and Cruiser®. The phytosanitary products applied to the crop predecessor to soybean in the 2019/2020 harvest are shown in Table 2. The specific details regarding the applied phytosanitary products are necessary, as many of these products can reduce the populations of springtails (Frampton & Wratten, 2000; Carniel et al., 2019).

Table 2. Phytosanitary products applied to the crop prior to soy cultivation (2019/2020 harvests) and the dates of the last application (DLA) for each class of product applied. Londrina, State of Paraná, 2020

	Treatments					
	T1	T2	T3	T4	T5	T6
Predecessor crop	Corn	Wheat	*Braquiaria*	Canola	Buckwheat + Black oats	Common bean
Herbicides	Atrazina®	Ally®	-	-	-	Gramoxone®
	Soberan®	-	-	-	-	Flex®
	-	-	-	-	-	Select®
DLA	09/04/2019	22/05/2019	-	-	-	23/04/2019
Insecticides	Platineo Neo®	Engeo Pleno®	-	-	-	-
	Galil®	Premio®	-	-	-	-
DLA	25/03/2019	25/06/2019	-	-	-	-
Fungicides	-	Nativo® + Mancozeb®	-	-	-	Mertin®
	-	Nativo® + Mancozeb®	-	-	-	-
	-	Nativo® + Mancozeb®	-	-	-	-
DLA	-	29/07/2019	-	-	-	26/04/2019

2.3 Soil Chemical and Dry Straw Mass Analyses

In September of 2019, after the winter season and before sowing the soybean, a chemical analysis from a soil sample was taken from each plot in the different rotation/succession systems. With the aid of an auger, with four points per plot, the soil was collected at a depth of 0-10 cm and taken to the laboratory to determine the following variables: pH in 0.01 M $CaCl_2$; calcium (Ca), magnesium (Mg) and aluminum (Al) contents by the KCl 1M extractor; potassium (K) and phosphorus (P) contents by the Mehlich-1 extractor; potential acidity (H + Al) by SMP; total organic carbon (TOC) by the Walkley and Black method; cation exchange capacity (T) and base saturation (V) were also estimated (Pavan et al., 1992). The results of the chemical analysis of the soil are represented in Table 3.

Table 3. Chemical analysis of the soil (mean ± standard deviation) carried out after the 2019/2020 soy harvest, under different rotation/succession systems using no-tillage. Londrina, State of Paraná, 2020

Treatments	pH	Ca	Mg	K	Al	H+Al	T	V	S	P	COT
	$CaCl_2$ 0.01 M	---------------------------------- $cmol_c\ dm^{-3}$ ----------------------------------						%	-------- $mg\ dm^{-3}$ -------		$mg\ ha^{-1}$
T1	5.08±0.2	4.33±0.5	2.49±0.3	0.35±0.1	0.02±0.02	5.07±0.4	12.21±0.4	58.43±4.8	7.17±0.9	26.85±6.6	23.04±4.6
T2	5.13±0.3	4.27±1.0	2.61±0.6	0.24±0.1	0.03±0.05	5.05±0.8	12.17±0.8	57.96±9.0	7.12±1.6	21.46±8.0	25.74±3.3
T3	5.14±0.2	3.91±0.8	2.54±0.5	0.22±0.1	0.03±0.04	4.85±0.5	11.52±0.9	57.44±7.3	6.67±1.3	15.69±5.1	19.86±5.7
T4	5.08±0.1	4.01±0.8	2.38±0.4	0.18±0.1	0.01±0.01	5.11±0.3	11.68±0.6	55.90±5.5	6.57±1.2	22.01±14.8	24.04±1.7
T5	5.15±0.3	4.00±0.7	2.61±0.4	0.27±0.1	0.03±0.03	4.94±0.9	11.82±0.8	58.09±7.9	6.87±1.1	23.61±14.6	22.90±4.1
T6	4.93±0.1	3.58±0.5	2.31±0.3	0.21±0.02	0.06±0.06	5.57±0.02	11.66±0.8	51.94±3.4	6.10±0.8	25.94±8.6	24.14±2.3
C.V. (%)	4.5	12.6	14.7	35.9	114.1	10.9	4.7	9.7	12.7	46.6	16.4
Significance	n.s.*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Note. * n.s. indicates that it was not possible to verify a significant difference, Scott-Knott test (α = 5%).

During the soil collection, in an area of 0.5 × 0.5 m from each plot, a sample of straw from the predecessor crop was taken. These samples were dried in a forced ventilation oven at 60 °C for 72 hours to determine the dry mass.

2.4 Springtail Sampling

In the 2019/2020 harvest, when the soybean crop was in the V4 development stage, springtails were sampled using pitfall traps (De Camargo et al., 2015), which are consisted of cylindrical plastic pots (14 cm in diameter × 9 cm in height), containing 200 mL of aqueous solution with 1% formaldehyde and 1% detergent.

In each plot, three traps were buried with an open end at ground level and remained in the field for 72 hours. Subsequently, the traps were removed, and the collected content was washed under running water in a set of sieves. The material retained in the sieves with a 5 mm mesh were discarded, the content retained in the 0.044 mm mesh sieve was conditioned in 70% alcohol and kept under refrigeration (< 0 °C), for later identification and quantification of the specimens, with the aid of a stereoscope microscope. Identification was performed up to Order as proposed by Rafael et al. (2012).

2.5 *Statistical Analysis*

The data collected of each chemical attribute of the soil, amount of straw from the crop prior to soybean cultivation and abundance of springtails were complacent with normality and homogeneity assumptions. After that, followed tests of variance, with means compared by the Scott Knott test at 5% significance. Pearson's correlation test (r) was performed between the amount of straw from the crop prior to soybean cultivation and the abundance of springtail.

3. Results

A total of 196,050 springtails specimens were collected, belonging to three taxonomic orders: Entomobryomorpha, Poduromorpha and Symphypleona. The order Poduromorpha was the most abundant, representing 87.6% of the specimens collected, followed by the order Entomobryomorpha and Symphypleona, representing 21.1% and 0.3%, respectively. In addition, the largest number of springtails were captured in the rotation/succession systems adopted in the T1, T3 and T4 treatments, between 21% and 22.5% of the collected specimens; however, the lowest amount was observed in T2, with 9.2% of the specimens collected (Table 4).

Table 4. Abundance (total values) and relative frequency (RF. %) of different springtail orders, collected using fall traps (Pitfall), in different rotation/succession systems using no-tillage. Londrina, State of Paraná, 2020

Treatment	Straw from the predecessor to soy cultivation	Springtail Order			Total	RF. %.
		Poduromorpha	Entomobryomorpha	Symphypleona		
T1	Corn	37564	3647	13	41224	21.0
T2	Wheat	13335	4602	20	17957	9.2
T3	*Braquiaria*	41807	2178	60	44045	22.5
T4	Canola	37669	4648	26	42343	21.6
T5	Buckwheat/Oats	17795	4305	11	22111	11.3
T6	Common bean	23720	4265	391	28376	14.4
Total		171890	23645	521	196056	100.0
RF. %		87.6	12.1	0.3		

The rotation/succession systems adopted in the T1, T3 and T4 treatments resulted in the greatest abundance of springtails, with average values of 10.3 to 11.0 thousand individuals collected, differing from the systems adopted in T2, T5 and T6, in which only 4.5 to 7.1 thousand specimens were collected (Figure 1).

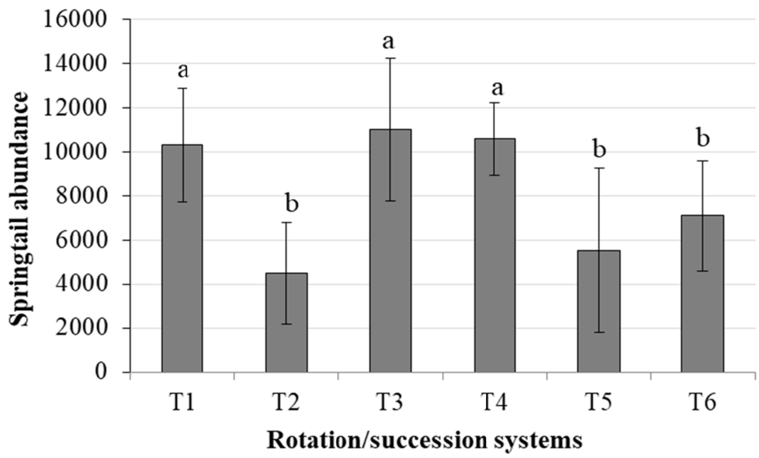

Figure 1. Abundance of springtails (average values, n = 4), collected using fall traps (Pitfall), in different rotation/succession systems using no-tillage. Londrina. State of Paraná, 2020. Bars in the columns indicate the standard deviation and distinct letters indicate significant differences following the Scott-Knott test (α = 5%)

The vegetal cover can influence the presence of springtails (Chauvat et al., 2003), thus, the straw dry mass remaining from the cultivation prior to soy was analyzed. It revealed that wheat (T2) and *Brachiaria* sp. (T3) crops provided the largest quantities of straw, with 6.1 and 6.6 ton ha^{-1}, respectively; while the consortium of buckwheat with oat (T5) and the cultivation of common bean (T6) resulted in the smallest quantities of straw remaining, with 2.3 and 2.2 ton ha^{-1}, respectively. The crops with corn (T1) and canola (T4), provided intermediate amounts of straw (5.0 ton ha^{-1}) (Figure 2).

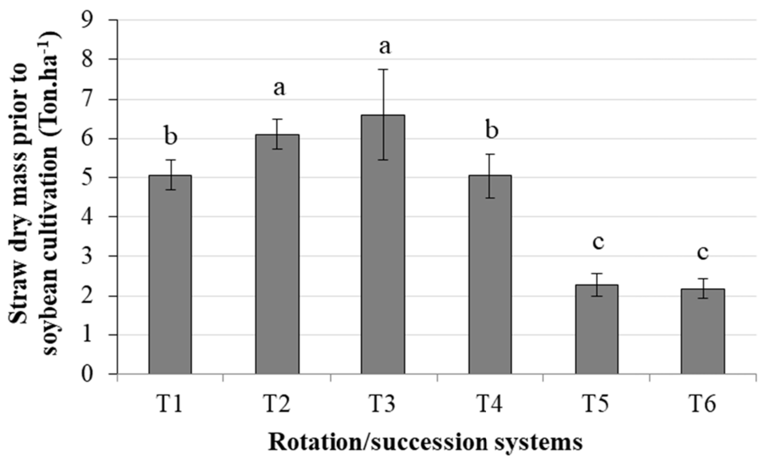

Figure 2. Straw dry mass (average values, n = 4), from the predecessor crop to soybean, in different rotation/succession systems using no-tillage. Londrina, State of Paraná, 2020. Bars in the columns indicate the standard deviation and distinct letters indicate significant differences following the Scott-Knott test (α = 5%)

The lowest quantities of straw reminiscent from soybean cultivation (Figure 2), resulted in the smallest number of springtails, with the exception of the T2 treatment (Figure 1). Although, the correlation between springtail abundance and the amount of remaining straw was not significant ($r = 0.33$; $p = 0.11$), when considering all rotation/succession systems. However, when the T2 treatment was removed from the analysis, due to the excessive phytosanitary products application (Table 2), a significant correlation was verifired ($r = 0.63$; $p < 0.01$), indicating that greater amounts of vegetation cover favor springtail populations.

4. Discussion

Since springtail populations can be influenced by soil pH (Chagnon et al., 2000, 2001; Ponge, 2000), calcium, magnesium, and total carbon content (Machado et al., 2019), chemical analysis of the soil was carried out. However, there were no significant differences in the chemical attributes evaluated between the different rotation/succession systems adopted (Table 3), indicating that the differences observed in springtail abundance (Figure 1) are related to other factors.

The loss of vegetal cover reduces the population and variability of species of springtails (Loranger et al., 1998), on the other hand, layers of vegetal cover favor the abundance of springtails (Jandl et al., 2003), due to better survival conditions (Moço et al., 2005), since the vegetal cover serves as a shelter for these organisms (Baretta et al., 2003) and the straw provides food for most organisms that live in the soil (Silva et al., 2006, 2013), these vegetal cover benefits could explain the greater springtail amounts in the treatments with higher remaining straw, in accordance with the correlation found when treatment 2 was removed.

Lucero et al. (2020), when evaluating the abundance of soil organisms with five different vegetal coverings, found that springtails were the most abundant organisms in the area with wheat cover and in the turnip/ryegrass consortium, differing from the results found in this study, since the smallest populations of springtails occurred when the predecessor crop was wheat (T2). However, when analyzing the history of predecessor crops to soybean, there is a greater application of phytosanitary products in the wheat crop, mainly fungicides (three applications of Nativo® + Mancozeb®). In addition, the shortest time elapsed between the application of fungicides and the gathering of springtails also occurred during the cultivation of wheat (Table 2).

Studies show that fungicides negatively affect springtails in laboratory tests (Frampton, 1998) and in field conditions in wheat crops (Frampton & Wratten, 2000). The indirect effect of the use of fungicides on the populations of springtails can be attributed to the elimination of many fungi, which serve as food for several species of springtails (Scheu & Folger, 2004; Sawahata, 2006). In addition, Carniel et al. (2019), found that the application of the fungicide Mancozebe® reduces the survival and reproduction of springtails.

The application of fungicides and the shorter time between the application and gathering of springtails, probably caused the population decline of these organisms, even under conditions of large amounts of straw that the wheat provided, justifying the results obtained in this work.

In general, the populations of springtails are influenced both by the vegetal cover and by the amount of fungicide applied on the soil. However, the use of the springtail populations as bioindicators of soil quality should be carried out with caution, since their populations may, in a short period of time, recover from disturbances caused to the soil, and not reflect a cumulative effect over several years. For a better indication of soil fertility, other attributes should also be monitored.

5. Conclusion

The largest springtails populations occur in the rotation/succession systems in which the preceding culture provides a greater vegetal cover amount.

Fungicide applications can reduce springtail population.

Cultivating *Brachiaria* sp., canola, corn and wheat provide greater amounts of straw, compared to the consortium of buckwheat with oats and common bean cultivation.

References

Alves, M. V., Baretta, D., & Cardoso, E. J. B. N. (2006). Fauna edáfica em diferentes sistemas de cultivo no Estado de São Paulo. *Revista de Ciências Agroveterinárias, 5*, 33-43.

Alves, P. R. L., & Cardoso, E. J. B. N. (2016). Overview of the standard methods for soil ecotoxicology testing. In M. L. Larramendy & S. Soloneski (Eds.), *Invertebrates—Experimental Models in Toxicity Screening* (pp. 35-56). IntechOpen. https://doi.org/10.5772/62228

Antoniolli, Z. I., Conceição, P. C., Böck, V., Port, O., Da Silva, D. M., & Da Silva, R. F. (2006). Método alternativo para estudar a fauna do solo. *Ciência Florestal, 16*, 407-417. https://doi.org/10.5902/198050981922

Baretta, D., Bartz, M. L. C., Fachini, I., Anselmi, R., Zortéa, T., & Baretta, C. R. D. M. (2014). Soil fauna and its relation with environmental variables in soil management systems. *Revista Ciência Agronômica, 45*, 871-879. https://doi.org/10.1590/S1806-66902014000500002

Baretta, D., Santos, J. C. P., Bertol, I., Alves, M. V., Manfoi, A. F., & Baretta, D. M. (2006). Efeito do cultivo do solo sobre a diversidade da fauna edáfica no planalto sul catarinense. *Revista de Ciências Agroveterinárias, 5*, 108-117.

Baretta, D., Santos, J. C. P., Mafra, Á. L., Do Prado, W. L., & Miquelluti, D. J. (2003). Fauna edáfica avaliada por armadilhas e catação manual afetada pelo manejo do solo na região oeste catarinense. *Revista de Ciências Agroveterinárias, 2*, 97-106.

Bedano, J. C., Domínguez, A., Arolfo, R., & Wall, L. G. (2016). Effect of good agricultural practices under no-till on litter and soil invertebrates in areas with diferente soil types. *Soil and Tillage Research, 158*, 100-109. https://doi.org/10.1016/j.still.2015.12.005

Bellinger, P. F., Christiansen, K. A., & Janssens, F. (2020). *Checklist of the Collembola of the world*. Retrieved September 24, 2020, from http://www.collembola.org

Bolliger, A., Magid, J., Amado, T. J. C., Skora Neto, F., Ribeiro, M. F. S., Calegari, A., ... Neergaard, A. (2006). Taking stock of the Brazilian "Zero-till revolution": A review of landmark research and farmers' practice. *Advances in Agronomy, 91*, 1-64. https://doi.org/10.1016/S0065-2113(06)91002-5

Carniel, L. S. C., Niemeyer, J. C., de Oliveira Filho, L. C. I., Alexandre, D., Gebler, L., & Klauberg-Filho, O. (2019). The fungicide mancozeb affects soil invertebrates in two subtropical Brazilian soils. *Chemosphere, 232*, 180-185. https://doi.org/10.1016/j.chemosphere.2019.05.179

Chagnon, M., Paré, D., & Hébert, C. (2000). Relationships between soil chemistry, microbial biomass and the collembolan fauna of southern Quebec sugar maple stands. *Ecoscience, 7*, 307-316. https://doi.org/10.1080/11956860.2000.11682600

Chagnon, M., Paré, D., Hébert, C., & Camiré, C. (2001). Effects of experimental liming on collembolan communities and soil microbial biomass in a southern Quebec sugar maple (*Acer saccharum* Marsh.) stand. *Applied Soil Ecology, 17*, 81-90. https://doi.org/10.1016/S0929-1393(00)00134-7

Chauvat, M., Zaitsev, A. S., & Wolters, V. (2003). Successional changes of Collembola and soil microbiota during forest rotation. *Oecologia, 137*, 269-276. https://doi.org/10.1007/s00442-003-1310-8

Crouau, Y., Chenon, P., & Gisclard, C. (1999). The use of Folsomia candida (Collembola, Isotomidae) for the bioassay of xenobiotic substances and soil pollutants. *Applied Soil Ecology, 12*(2), 103-111. https://doi.org/10.1016/S0929-1393(99)00002-5

Culik, M. P., & Zeppelini Filho, D. (2003). Diversity and distribution of collembola (arthropoda: hexapoda) of Brazil. *Biodiversity & Conservation, 12*(6), 1119-1143. https://doi.org/10.1023/A:1023069912619

Damé, P. R. V., Quadros, F. L. F., Kersting, C. E. B., Trindade, J. P. P., & Antoniolli, Z. I. (1996). Efeitos da queimada seguida de pastoreio ou diferimento sobre o resíduo, temperatura do solo e mesofauna de uma pastagem natural. *Ciência Rural, 26*, 391-396. https://doi.org/10.1590/S0103-84781996000300008

De Camargo, A. J. A., De Oliveira, C. M., Frizzas, M. R., Sonoda, K. C., & Corrêa, D. (2015). *Coleções entomológicas: Legislação brasileira, coleta, curadoria e taxonomias para as principais ordens*. Embrapa Cerrados-Livro Científico (ALICE).

Duda, G. P., Guerra, J. G. M., Monteiro, M. T., De-Polli, H., & Teixeira, M. G. (2003). Perennial herbaceous legumes as live soil mulches and their effects on C, N and P of the microbial biomass. *Scientia Agricola, 60*,139-147. https://doi.org/10.1590/S0103-90162003000100021

Eisenbeis, G. (1983). Kinetics of water exchange in soil arthropods. *International Colloquium of Soil Zoology, 8*, 417-425.

Frampton, G. K. (1988). The effects of some commonly - used foliar fungicides on Collembola in winter barley: laboratory and field studies. *Annals of Applied Biology, 113*(1), 1-14. https://doi.org/10.1111/j.1744-7348.1988.tb03276.x

Frampton, G. K., & Wratten, S. D. (2000). Effects of benzimidazole and triazole fungicide use on epigeic species of Collembola in wheat. *Ecotoxicology and Environmental Safety, 46*(1), 64-72. https://doi.org/10.1006/eesa.1999.1874

Gatiboni, L. C., Coimbra, J. L. M., Wildner, L. P., & Denardin, R. B. N. (2009). Modificações na fauna edáfica durante a decomposição da palhada de centeio e aveia-preta, em sistema plantio direto. *Biotemas, 22*, 45-53. https://doi.org/10.5007/2175-7925.2009v22n2p45

Hojer, R., Bayley, M., Damgaard, C. F., & Holmstrup, M. (2001). Stress synergy between drought and a common environmental contaminant: Studies with the collembolan Folsomia candida. *Global Change Biology, 7*, 485-494. https://doi.org/10.1046/j.1365-2486.2001.00417.x

Holmstrup, M., Bindesbøl, A. M., Oostingh, G. J., Duschl, A., Scheil, V., Köhler, H. R., … Spurgeon, D. J. (2010). Interactions between effects of environmental chemicals and natural stressors: A review. *Science of the Total Environment, 408*(18), 3746-3762. https://doi.org/10.1016/j.scitotenv.2009.10.067

IDR-PR (Instituto de Desenvolvimento Rural do Paraná). (2020). *Atlas climático*. Retrieved September 28, 2020, from http://www.idrparana.pr.gov.br/Pagina/Atlas-Climatico

Jandl, R., Kopeszki, H., Bruckner, A., & Hager, H. (2003). Forest soil chemistry and mesofauna 20 years after an amelioration fertilization. *Restoration Ecology, 11*, 239-246. https://doi.org/10.1046/j.1526-100X.2003.00179.x

Jänsch, S., Amorim, M. J., & Rombke, J. (2005). Identification of the ecological requirements of important terrestrial ecotoxicological test species. *Environmental Reviews, 13*, 51-83. https://doi.org/10.1139/a05-007

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., … Rossi, J. P. (2006). Soil invertebrates and ecosystem services. *European Journal of Soil Biology, 42*, 3-15. https://doi.org/10.1016/j.ejsobi.2006.10.002

Leal, A. J. F., Lazarini, E., Tarsitano, M. A. A., De Sá, M. E., & JúnioR, F. G. G. (2005). Viabilidade econômica da rotação de culturas e adubos verdes antecedendo o cultivo do milho em sistema de plantio direto em solo de cerrado. *Revista Brasileira de Milho e Sorgo, 4*(3), 298-307. https://doi.org/10.18512/1980-6477/rbms.v4n3p298-307

Lima, A. C. R., Brussaard, L., Totola, M. R., Hoogmoed, W. B., & Goede, R. G. M. (2013). A functional evaluation of three indicator sets for assessing soil quality. *Applied Soil Ecology, 64*, 194-200. https://doi.org/10.1016/j.apsoil.2012.12.009

Loranger, G., Ponge, J. F., Blanchart, É., & Lavelle, P. (1998). Influence of agricultural practices on arthropod communities in a vertisol (Martinique) (1999). *European Journal of Soil Biology, 34*, 157-165. https://doi.org/10.1016/S1164-5563(00)86658-3

Lucero, E. M., Vieira, R. C. B., & Vieira, Â. D. H. N. (2020). Invertebrados edáficos em culturas de verão e inverno no noroeste do Rio Grande do Sul. *Revista Brasileira de Agropecuária Sustentável, 10*, 67-74. https://doi.org/10.21206/rbas.v10i1.9281

Machado, J. D. S., Oliveira Filho, L. C. I., Santos, J. C. P., Paulino, A. T., & Baretta, D. (2019). Morphological diversity of springtails (Hexapoda: Collembola) as soil quality bioindicators in land use systems. *Biota Neotropica, 19*, 1-11. https://doi.org/10.1590/1676-0611-BN-2018-0618

Menezes, L. A. S., & Leandro, W. M. (2004). Avaliação de espécies de coberturas do solo com potencial de uso em sistema de plantio direto. *Pesquisa Agropecuária Tropical, 34*, 173-180.

Moço, M. K. D. S., Gama-Rodrigues, E. F. D., Gama-Rodrigues, A. C. D., & Correia, M. E. F. (2005). Caracterização da fauna edáfica em diferentes coberturas vegetais na região norte fluminense. *Revista Brasileira de Ciência do Solo, 29*, 555-564. https://doi.org/10.1590/S0100-06832005000400008

Pavan, M. A., Bloch, M. F., Zempulski, H. C., & Miyazawa, M. (1992). *Manual de análise química de solo e controle de qualidade* (Circular Técnica, 76). Londrina, PR: IAPAR.

Peijnenburg, W., Capri, E., Kula, C., Liess, M., Montforts, M., Nienstedt, K., ... Jensen, J. (2012). Evaluation of exposure metrics for effect assessment of soil invertebrates. *Critical Reviews in Environmental Science and Technology, 42*, 1862-1893. https://doi.org/10.1080/10643389.2011.574100

Ponge, J. F. (2000). Acidophilic Collembola: Living Fossils? *Contrib. Biol. Lab. Kyoto Univ., 29*,65-74.

Rafael, J. A., Melo, G. A. R., Carvalho, C. J. B. D., Casari, S. A., & Constantino, R. (2012). *Insetos do Brasil: diversidade e taxonomia* (p. 810). Ribeirão Preto: Editora Hollos.

Rusek, J. (1998). Biodiversity of Collembola and their functional role in the ecosystem. *Biodiversity and Conservation, 7*, 1207-1219. https://doi.org/10.1023/A:1008887817883

Santos, D. P., Santos, G. G., Santos, I. L. D., Schossler, T. R., Niva, C. C., & Marchão, R. L. (2016). Caracterização da macrofauna edáfica em sistemas de produção de grãos no Sudoeste do Piauí. *Pesquisa Agropecuária Brasileira, 51*(9), 1466-1475. https://doi.org/10.1590/s0100-204x2016000900045

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., … Cunha, T. J. F. (2018). *Sistema brasileiro de classificação de solos* (5th ed.). Brasília, DF: Embrapa.

Sawahata, T. (2006). Hymenial area of agaric fruit bodies consumed by Collembola. *Mycoscience, 47*, 91-93. https://doi.org/10.1007/S10267-005-0272-6

Scheu, S., & Folger, M. (2004). Single and mixed diets in Collembola: effects on reproduction and stable isotope fractionation. *Functional Ecology, 18*(1), 94-102. https://doi.org/10.1046/j.0269-8463.2004.00807.x

Silva, D. A., Silva, D. M., Jacques, R., & Antoniolli, Z. (2015). Bioindicadores de qualidade edáfica em diferentes usos do solo. Enciclopedia biósfera, 11(22). https://doi.org/10.18677/Enciclopedia_Biosfera_2015_260

Silva, R. F. D., Aquino, A. M. D., Mercante, F. M., & Guimarães, M. D. F. (2006). Macrofauna invertebrada do solo sob diferentes sistemas de produção em Latossolo da Região do Cerrado. *Pesquisa AgropecuÁRia Brasileira, 41*, 697-704. https://doi.org/10.1590/S0100-204X2006000400022

Teixeira, P. C., Donagemma, G. K., Fontana, A., & Teixeira, W. G. (2017). *Manual de métodos de análise de solo* (p. 573). Rio de Janeiro, Embrapa.

Warren, M. W., & Zou, X. (2002). Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico. *Forest Ecology and Management, 170*, 161-171. https://doi.org/10.1016/S0378-1127(01)00770-8

Wink, C., Guedes, J. C., Fagundes, C. K., & Rovedder, A. P. (2005). Insetos edáficos como indicadores de qualidade ambiental. *Revista de Ciências Agroveterinária, 4*, 60-71.

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