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Article

PEREIRA, J.L.[1]*
ARAÚJO, T.A.[1]
RODRIGUES-SILVA, N.[1]
SILVA, A.A.[1]
PICANÇO, M.C.[1]

EDAPHIC ENTOMOFAUNA VARIATION DEPENDING ON GLYPHOSATE APPLICATION IN ROUNDUP READY SOYBEAN CROPS

Variação da Entomofauna Edáfica em Função da Aplicação do Glyphosate em Cultivos de Soja Roundup Ready

ABSTRACT - Currently, biomonitoring is a methodology used to verify the environmental impact of new technologies in the agricultural environment, highlighting edaphic entomofauna that is traditionally used as a bioindicator in this sort of research. Therefore, the objective of this study was to investigate the edaphic entomofauna variation depending on glyphosate application in Roundup Ready soybeans. The experiment was carried out in Coimbra, MG during the 2007/2008 and 2008/2009 cropping seasons. The experimental design was a randomized block design with five replications. The treatments were: non-transgenic soybean with mechanical weeding of weeds; transgenic soybean with mechanical weeding of weeds; transgenic soybean with one glyphosate application and transgenic soybean with three glyphosate applications. The populations of the edaphic entomofauna were sampled during two crops. The insertion of the glyphosate tolerance gene did not affect the richness and the abundance of arthropods in the soil. The arthropod richness was reduced in treatments where glyphosate was applied one and three times. The glyphosate application in transgenic soybean reduced the density of the predatory mite Galumnidae (Acari); predator ants *Neivamyrmex* sp. (Hymenoptera: Formicidae) and *Solenopsis* sp. (Hymenoptera: Formicidae); and springtails Entomobryidae (Collembola), *Hypogastrura* sp. (Collembola: Hypogastruridae) and Onychiuridae (Collembola). Therefore, it is essential to follow the use recommendations of the herbicide glyphosate and adopt good agricultural practices that promote pesticide biodegradation, thereby contributing to the reduction of the toxicological potential of glyphosate on the edaphic entomofauna.

Keywords: *Glycine max*, bioindicators, transgenic plants, herbicide.

RESUMO - Atualmente, o biomonitoramento tem sido uma metodologia bastante adotada para se verificar o impacto ambiental das novas tecnologias no meio agrícola, com destaque para a entomofauna edáfica, que é tradicionalmente utilizada como bioindicadora nesse tipo de pesquisa. Assim, objetivou-se com este estudo investigar a variação da entomofauna edáfica em função da aplicação do herbicida glyphosate em cultivos de soja Roundup Ready. O experimento foi realizado em Coimbra, MG, nas safras agrícolas de 2007/2008 e 2008/2009. Utilizou-se o delineamento experimental em blocos casualizados com cinco repetições. Os tratamentos estudados foram: soja não transgênica com capina mecânica das plantas daninhas; soja transgênica com capina mecânica das plantas daninhas; soja transgênica com uma aplicação de glyphosate; e soja transgênica com três aplicações de glyphosate. As populações da entomofauna edáfica foram amostradas ao longo dos dois cultivos. A inserção do gene de tolerância ao

*** Corresponding author:**
<tamirisaa@gmail.com>

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[1] Universidade Federal de Viçosa, Viçosa-MG, Brazil.

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herbicida glyphosate não afetou a riqueza e a abundância de artrópodes do interior do solo. A riqueza dos artrópodes foi reduzida nos tratamentos que receberam uma e três aplicações de glyphosate. A aplicação de glyphosate na soja transgênica reduziu a densidade do ácaro predador Galumnidae (Acari); das formigas predadoras ***Neivamyrmex*** *sp. (Hymenoptera: Formicidae) e* ***Solenopsis*** *sp. (Hymenoptera: Formicidae); e dos colêmbolos Entomobryidae (Collembola),* ***Hypogastrura*** *sp. (Collembola: Hypogastruridae) e Onychiuridae (Collembola). Diante disso, torna-se essencial atender às recomendações de uso do herbicida glyphosate e adotar boas práticas culturais que favoreçam a biodegradação de pesticidas, para assim contribuir com a redução do potencial toxicológico do glyphosate sobre a entomofauna edáfica.*

Palavras-chave: *Glycine max*, bioindicadores, plantas transgênicas, herbicida.

INTRODUCTION

Edaphic fauna is commonly used as a bioindicator in studies involving detection and monitoring of the environmental quality (Paoletti et al., 2007; Zhang et al., 2014). Among the bioindicators in the soil, the arthropods stand out because of their great species and habitat diversity, and because they are involved in biological processes of natural ecosystems. In addition, arthropods are sensitive to changes of the environment, and so can be used in monitoring environmental disturbances (Barbercheck et al., 2009; Prosser et al., 2016).

The use of the arthropod edaphic community as a tool for environmental impact studies has evolved with the development of multivariate data analyses. These analyses allow for an increase in the generation of hypothesis, which allows the data set to be summarized and simplified information without losing the statistical power. Multivariate analysis is used when there is a necessity to simultaneously study a series of variables which can be associated with a particular phenomenon (Anderson, 2003). Therefore, in outdoor studies where the majority of the conditions are not controlled, this tool becomes essential.

In this context, studies involving a possible impact of the effects of genetically modified organisms on the environment through biomonitoring are a potentiality. Today, there are many discussions about this technology; however, only a few studies are developed with the goal to detect the real impact of this technology on the agroecosystem balance. The advent of glyphosate-resistant transgenic soybeans led to increased glyphosate herbicide application (Owen et al., 2015). The herbicides used may promote harmful effects to the entomofauna, though the magnitude of response can be more directly related to indirect effects caused by changes to habitat (Prosser et al., 2016). Some of these effects can be caused by loss of vegetal cover as a function of the weeds, thereby decreasing food resources and shelter for some arthropods species (Norris and Kogan, 2000).

Considering the potential of edaphic arthropods as bioindicators and the information scarceness about the environmental impact of transgenic technology on the agroecosystem, the objective of this study is to evaluate the edaphic entomofauna variation as a function of glyphosate application on Roundup Ready® (RR) soybean.

MATERIAL AND METHODS

The experiment was carried out at Coimbra, MG, during the 2007/2008 and 2008/2009 cropping seasons. The soybean varieties used were BRS Favorita RR (Roundup Ready®) transgenic soybean and MG/BR-46 Conquista non-transgenic soybean. Soybean direct seeding was performed in the first half of December during the 2007/2008 cropping season, and in the second half of November in the 2008/2009 cropping season. Daily values of air temperature (maximum, average, and minimum), relative humidity and rainfall during the crop cycle during the experimental period were recorded by a meteorological station installed at the crop site (Figure 1).

The experimental design was completely randomized with 5 replications. Each experimental plot was 10 x 10 m area, with 0.5 m between rows and a plant density of 18 seeds per linear meter. The treatments were: 1 - non-transgenic soybean with mechanical weeding; 2 - transgenic

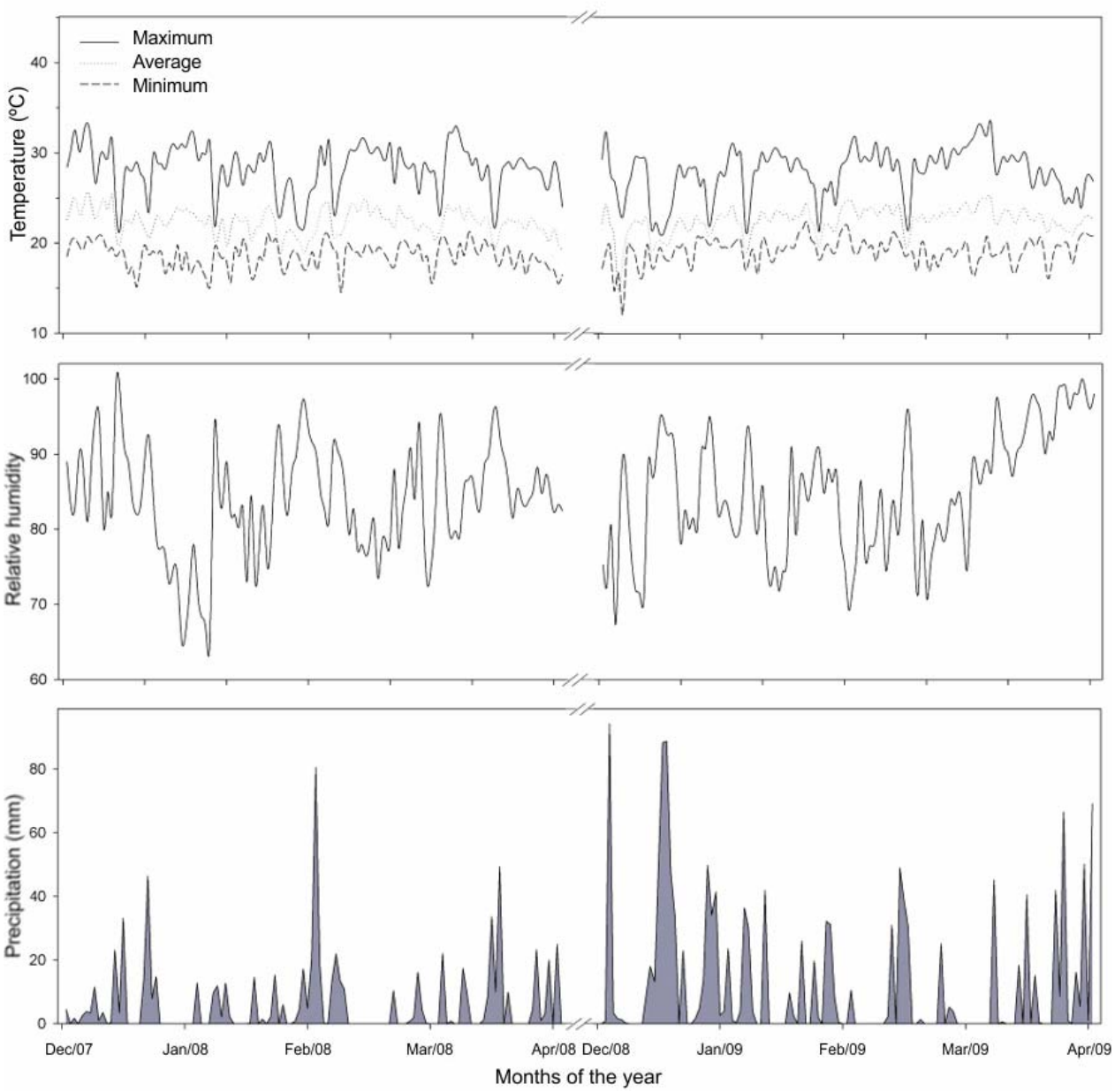

Figure 1 - Air temperatures (maximum, average and minimum), relative humidity and rainfall during two soybean crops. Coimbra, MG, 2007-2009.

soybean with mechanical weeding; 3 - transgenic soybean with one glyphosate application (1.080 a.i. g. ha^{-1}) at 15 days after seedling emergence; and 4 - transgenic soybean with three glyphosate applications (1.080 a.i. g. ha^{-1}) at 15, 30, and 45 days after seedling emergence.

The arthropod populations of the soil interior were evaluated at the first cropping season at 10, 26, 39, 52, 65, and 92 days after seedling emergence. At the second cropping season, the arthropod populations were evaluated at 10, 17, 31, 49, 72, 90, and 106 days after seedling emergence. Samples were collected by removing soil blocks 30 cm deep x 10 cm in diameter. The soil blocks were placed in Berlese funnels for 48 hours (Wardle and Yeates, 1993). Arthropods captured by Berlese funnel were collected in glass jars containing alcohol 70%. Afterwards, the arthropods were transferred to Petri dishes (9 x 2 cm, diameter, and height, respectively) for counting the total arthropods number using a stereoscopic microscope with a fixed magnification of 12X.

The mites were identified by Dr. Jeferson Luiz de Carvalho Mineiro, from the Instituto Biológico (Campinas, SP). The springtails were identified by Dr. Elisiana Oliveira, from the Instituto Nacional

de Pesquisa da Amazônia de Manaus (INPA). The beetles were identified by Dr. Antonio Domingos Brescovit, from the Instituto Butantan (São Paulo, SP). The ants were identified by Dr. Cidália Gabriela Santos Marinho, from the Universidade Federal de Campina Grande (Campina Grande, Paraíba). The specimens of the other orders were collected and identified at the family level, and when possible, to genus and species, using taxonomic keys and the reference collection of the entomology museum at Universidade Federal de Viçosa (Viçosa, MG).

The richness was represented for the species total number and species number represented in each guild for each treatment for both experimental periods. In the case of the relative abundance, data underwent a selection process to determine the more abundant species for both experimental periods which justified the observed variance (PROC STEPDISC, STEPWISE, Program Statistical Analysis System – SAS, 2013). The data for species selected underwent Canonical Variate Analysis (CVA). The significant difference of the arthropod community abundance as a function of the treatments was verified by F-test (p-value < 0.05), associated with the Mahalanobis distance between class means. For the species which best explained the maximum discrimination between treatments, population fluctuation curves (mean ± standard error) were generated for each treatment for both experimental periods. The relative abundance data of these species were analyzed by analysis of variance by repeated measures to determine which treatments had an effect for each experimental period.

RESULTS AND DISCUSSION

During the first experimental period, 122 soil arthropod species were observed. Among these species, 13 were chewing phytophagous species, 15 were sucking phytophagous species, 50 were predators, 2 were parasitoids, and 42 were detritivores. The total arthropod richness ranged from 73 species for non-transgenic soybean with mechanical weeding, to 64 species for transgenic soybean with three glyphosate applications. During the second experimental period, 110 soil arthropod species were observed. Among these species, 10 were chewing phytophagous species, 16 were sucking phytophagous species, 52 were predators, 2 were parasitoids, and 30 were detritivores. The total arthropod richness ranged from 61 species for transgenic soybean with mechanical weeding, to 41 species for transgenic soybean with three glyphosate applications (Table 1).

Among 131 and 108 arthropods species observed for first and second experimental periods, respectively, 14 species had a frequency of occurrence higher than 10%. The arthropods of higher

Table 1 - Total of detritivores, phytophages (chewers and suckers), predators, parasitoids and total species per guild captured within the soil of transgenic soybean (TS) and non-transgenic soybean (NTS) with one and three applications of glyphosate (1Gly and 3Gly). Coimbra, MG, 2007-2009

Guild	Wealth (number of species/treatment)				Total species per guild
	NTS	TS	TS-1Gly	TS-3Gly	
2007/2008					
Chewing phytophagous	7	9	5	8	13
Sucking phytophagous	11	7	6	7	15
Predators	32	33	24	24	50
Parasitoids	1	1	1	0	2
Detritivores	22	22	19	18	42
Total	73	72	65	64	122
2008/2009					
Chewing phytophagous	5	6	4	4	10
Sucking phytophagous	7	8	5	6	16
Predators	29	28	18	21	52
Parasitoids	0	2	0	0	2
Detritivores	18	17	15	15	30
Total	59	61	45	41	110

occurrence (>10%) in each guild, for both periods, were the predators Cosmolaelaps (Acari: Laelapidae), Galumnidae (Acari), *Hypoaspis* sp. (Acari: Laelapidae), *Neivamyrmex* sp. (Hymenoptera: Formicidae), *Pachycondyla* sp. (Hymenoptera: Formicidae), *Scytodes itapevi* (Araneae: Scytodidae), *Solenopsis* sp. (Hymenoptera: Formicidae) and *Tapinoma* sp. (Hymenoptera: Formicidae); the detritivores Entomobryidae (Collembola), *Hypogastrura* sp. (Collembola: Hypogastruridae), Isotomidae (Collembola), Onychiuridae (Collembola), Scheloribatidae (Acari); and Scirtidae (Coleoptera) larvae (Table 2).

Predators Cosmolaelaps, Galumnidae, *Neivamyrmex* sp. and *Solenopsis* sp., and detritivores *Hypogastrura* sp., Onychiuridae and Entomobryidae and Scirtidae larvae were the species which best explained the maximum discrimination among the treatments (Table 3). Based on canonical coefficients, the species which more positively contributed to the divergence among treatments at canonical axes were Cosmolaelaps (axis 1 for both periods), Galumnidae (axis 1 for both periods), *Neivamyrmex* sp. (axis 1 for both periods) and Onychiuridae (axis 2 for both periods). The species which most negatively contributed to a divergence among treatments at canonical axes were Cosmolaelaps (axis 2 for both periods) and Galumnidae (axis 2 for both periods) (Table 4). Therefore, predators Cosmolaelaps, Galumnidae and *Neivamyrmex* sp., and detritivores Onychiuridae were the main species with a predictive capacity for the treatment effects. Consequently, these species

Table 2 - Abundance (individuals/ sample) and frequency (freq.) of the most abundant arthropods (frequency>10%) in the soil in transgenic soybean (TS) and non-transgenic soybean (NTS) with one and three applications of glyphosate and 3Gly). Coimbra, MG, 2007-2009

Arthropods*	Guild*	Number of individuals/sample (mean ± standard error)				Freq. (%)
		NTS	TS	TS-1Gly	TS-3Gly	
	2007/2008					
Cosmolaelaps (Acari: Laelapidae) (Np + Ad)	Pd	1.54 ± 0.79	0.79 ± 0.99	0.62 ± 0.56	0.71 ± 0.60	31
Galumnidae (Acari) (Np + Ad)	Pd	5.16 ± 1.17	3.46 ± 1.06	1.29 ± 0.80	1.04 ± 0.67	64
Hypoaspis sp. (Acari: Laelapidae) (Np + Ad)	Pd	3.75 ± 1.12	3.17 ± 2.21	2.12 ± 2.36	4.21 ± 2.64	61
Neivamyrmex sp. (Hymenoptera: Formicidae) (Ad)	Pd	9.42 ± 3.31	9.00 ± 3.54	0.91 ± 1.24	1.04 ± 0.74	54
Pachycondyla sp. (Hymenoptera: Formicidae) (Ad)	Pd	0.25 ± 0.26	0.50 ± 0.59	0.21 ± 0.36	0.54 ± 0.82	15
Scytodes itapevi (Araneae: Scytodidae) (Im + Ad)	Pd	0.12 ± 0.17	0.17 ± 0.28	0.17 ± 0.19	0.12 ± 0.17	13
Solenopsis sp. (Hymenoptera: Formicidae) (Ad)	Pd	13.70 ± 3.70	11.95 ± 3.53	8.46 ± 3.06	5.00 ± 2.11	84
Tapinoma sp. (Hymenoptera: Formicidae) (Ad)	Pd	0.08 ± 0.14	0.08 ± 0.14	0.28 ± 0.17	0.42 ± 0.48	11
Entomobryidae (Collembola) (Im + Ad)	Dt	11.17 ± 4.19	9.29 ± 2.62	5.50 ± 1.54	5.21 ± 2.76	80
Hypogastrura sp. (Collembola: Hypogastruridae) (Im + Ad)	Dt	6.33 ± 1.87	6.08 ± 2.01	2.67 ± 2.18	3.46 ± 2.84	66
Isotomidae (Collembola) (Im + Ad)	Dt	11.17 ± 4.19	9.29 ± 2.62	5.50 ± 4.54	5.20 ± 2.76	63
Onychiuridae (Collembola) (Im + Ad)	Dt	9.08 ± 2.75	11.20 ± 2.85	5.75 ± 2.39	2.00 ± 1.51	71
Scheloribatidae (Acari) (Np +Ad)	Dt	1.91 ± 0.75	2.70 ± 3.20	2.12 ± 2.35	4.21 ± 2.64	58
Scirtidae (Coleoptera) (Lv)	Dt	1.37 ± 0.55	1.12 ± 0.56	0.75 ± 0.45	0.67 ± 0.52	51
	2008/2009					
Cosmolaelaps (Acari: Laelapidae) (Np + Ad)	Pd	1.93 ± 1.74	2.18 ± 1.86	0.21 ± 0.28	0.14 ± 0.22	29
Galumnidae (Acari) (Np + Ad)	Pd	7.04 ± 2.26	7.43 ± 2.56	2.78 ± 1.50	1.60 ± 1.13	79
Hypoaspis sp. (Acari: Laelapidae) (Np + Ad)	Pd	4.04 ± 2.98	2.93 ± 2.03	5.18 ± 2.97	2.43 ± 1.74	59
Neivamyrmex sp. (Hymenoptera: Formicidae) (Ad)	Pd	7.64 ± 2.79	8.64 ± 2.87	1.61 ± 1.16	1.89 ± 1.20	76
Pachycondyla sp. (Hymenoptera: Formicidae) (Ad)	Pd	0.86 ± 1.29	0.39 ± 0.85	0.14 ± 0.26	0.28 ± 0.57	11
Scytodes itapevi (Araneae: Scytodidae) (Im + Ad)	Pd	0.11 ± 0.16	0.18 ± 0.19	0.11 ± 0.16	0.04 ± 0.09	11
Solenopsis sp. (Hymenoptera: Formicidae) (Ad)	Pd	14.10 ± 3.71	13.28 ± 3.97	5.50 ± 2.58	4.14 ± 1.90	89
Tapinoma sp. (Hymenoptera: Formicidae) (Ad)	Pd	0.28 ± 0.51	0.50 ± 0.40	0.14 ± 0.23	0.18 ± 0.19	18
Entomobryidae (Collembola) (Im + Ad)	Dt	37.75 ± 15.71	31.21 ± 12.86	15.78 ± 7.99	10.32 ± 6.68	85
Hypogastrura sp. (Collembola: Hypogastruridae) (Im + Ad)	Dt	2.61 ± 1.14	2.60 ± 1.17	0.96 ± 0.81	1.11 ± 0.82	56
Isotomidae (Collembola) (Im + Ad)	Dt	2.07 ± 1.48	2.64 ± 1.67	7.50 ± 13.83	7.96 ± 13.14	59
Onychiuridae (Collembola) (Im + Ad)	Dt	11.54 ± 4.62	16.28 ± 6.12	9.50 ± 4.97	4.28 ± 2.50	84
Scheloribatidae (Acari) (Im +Ad)	Dt	1.75 ± 1.55	1.18 ± 0.96	3.32 ± 3.06	2.04 ± 1.58	38
Scirtidae (Coleoptera) (Lv)	Dt	1.14 ± 0.86	0.82 ± 0.43	0.43 ± 0.34	0.57 ± 0.46	48

* Im= Immature, Lv=larvae, Ad=adult, Np= Nymph, Pd=predator and Dt= Detritivores.

Table 3 - Selection summary by STEPWISE with SAS STEPWISE STEPDISC procedure, aiming to select species to be included in the analysis of canonical variables, obtaining maximum discrimination between treatments. Coimbra, MG, 2007-2009

Variable	Partial R^2	Test F – the analysis of covariance		Square partial correlation	
		F	p	Canonical correlation square average	p
Predators					
Cosmolaelaps	0.0723	5.17	0.0018	0.3092	<0.0001
Galumnidae	0.4481	55.22	<0.0001	0.1493	<0.0001
Neivamyrmex sp.	0.2307	20.20	<0.0001	0.2424	<0.0001
Solenopsis sp.	0.1243	9.51	<0.0001	0.2657	<0.0001
Detritivores					
Entomobryidae	0.0562	3.93	0.0094	0.3170	<0.0001
Hypogastrura sp.	0.0281	1.90	0.1311	0.3235	<0.0001
Onychiuridae	0.1041	7.75	<0.0001	0.2968	<0.0001
Scirtidae	0.3074	30.03	<0.0001	0.2082	<0.0001

Table 4 - Canonical axes and their coefficients (canonical structure) of the effect of non-transgenic soybean and transgenic soybean with one or three applications of glyphosate (1Gly and 3Gly) on the species selected by STEPWISE with SAS STEPDISC procedure STEPWISE. Coimbra, MG, 2007-2009

Variable	Canonical axes			
	1	2	1	2
	2007-2008		2008-2009	
Predators				
Cosmolaelaps	0.127	-0.147	0.113	0.062
Galumnidae	0.353	-0.191	0.158	-0.044
Neivamyrmex sp.	0.345	-0.039	0.110	0.015
Solenopsis sp.	0.058	0.060	0.079	0.010
Detritivores				
Entomobryidae	0.029	-0.058	0.025	0.003
Hypogastrura sp.	0.002	-0.054	0.063	0.103
Scirtidae	0.077	-0.013	0.122	0.847
F	7.01	1.68	11.64	2.81
Df (numerator/ denominator)	24/232	14/162	24/232	14/162
p	<0.0001	0.0435	<0.0001	0.0009
Partial canonical correlation	0.90	0.07	0.91	0.06

Df = Degrees of freedom.

contributed more information concerning the transgenic soybean and glyphosate application effects on these guilds.

Significant differences were observed among treatments for the first (Wilks' lambda = 0.2064 e F = 7.01 and df (numerator/denominator) = 24/273 and p<0.0001) and second (Wilks' lambda = 0.1645 and F = 9.93 and df (numerator/denominator) = 24/276 and p<0.0001) experimental periods. Four canonical axes were calculated, two axes being significant for the first period (p<0.0001 and p = 0.0435) and one axis for the second period (p<0.0001 and p = 0.060). The first and second canonical axes explained 90 and 7% of the accumulated variance for the first period, respectively, and 91 and 6% of the accumulated variance for the second period, respectively (Table 4).

During the experimental period, the average temperature was 22.5 °C, with temperature peaks above 33 °C duringt the second experimental period. The relative humidity remained above 60%, and rainiest period occurred during the second experimental period, mainly during

December and January (Figure 1). For both experimental periods, the species selected by CVA for the transgenic soybean with glyphosate herbicide application treatments had the lowest seasonal abundance, in contrast to treatments that included mechanical weeding (Figures 2 and 3).

Analysis of ordination diagrams for both experimental periods verified that transgenic soybean did not affect the arthropod total abundance (Figure 4). Moreover, significant differences were not observed for species densities selected by CVA among transgenic and non-transgenic soybean treatments (Tables 5 and 6). For both experimental periods, the effect of the transgenic soybean with glyphosate herbicide application decreases the arthropod total density. Significant difference was not observed among one and three glyphosate applications for the total arthropods density, however, the abundance of some selected species by CVA was affected. There was, for both periods, a decrease in predator density Galumnidae and *Neivamyrmex* sp. for transgenic soybean with one and three glyphosate applications, and *Solenopsis* sp. for transgenic soybean with three glyphosate applications (Table 5; Figure 2). For detritivores, for both periods, the were density reductions of the springtails Entomobryidae, *Hypogastrura* sp. and Onychiuridae for transgenic soybean with one or three glyphosate applications (Table 6; Figure 3).

Gene insertion of glyphosate herbicide tolerance did not influence the richness, total arthropod density, or the seasonality of arthropod species recovered. This demonstrates that the glyphosate resistance gene incorporation (CP4 EPSPS) of the bacterium *Agrobacterium* strain CP4 did not affect the total arthropod diversity of the soil interior. However, the arthropod richness decreased in the treatments which received the glyphosate application. Studies have reported that weed control in soybean has influenced the pest-arthropod and natural enemy abundance but reports about transgenic soybean influence on soil interior arthropod richness are lacking (Zeiss and Klubertanz, 1994; Norris and Kogan, 2000). Soil arthropods are considered good bioindicators of environmental impact (Paoletti et al., 2007; Zhang et al., 2014); therefore, the decrease of these organisms' diversity in fields with glyphosate application indicates the impact of using this herbicide. Decreases of the soil edaphic arthropod diversity, in turn, can favor the occurrence of agricultural pest outbreaks (Pedigo, 1999), because these organisms are important biological control agents.

The arthropod richness of the soil interior during the first experimental period was higher thanduring the second experimental period. Natural and anthropogenic disturbances can affect the structure of soil fauna because they affect the organic matter and vegetal abundance (Wagg et al., 2014). For example, a traditional monoculture induces rapid loss of the organic soil layer, mainly in tropical regions, reducing the available resources, and therefore changing the composition and density of the soil arthropod species (Haddad et al., 2009). In addition, macro and microclimate component variation, such as rainfall, photoperiod, temperature, and relative humidity, and the variation of decomposition rates and vegetal cover, among other factors, can influence arthropod community abundance dynamics (Danks, 2006; Vineesh et al., 2007). Rainfall occurrence can also decrease the arthropod diversity and density by raindrop impact or by organic matter reduction, which serves as a food and shelter resource for many soil arthropod species (Sundarapandian et al., 2005). Therefore, richness difference among both experimental periods can be related to higher rainfall during the second experimental period. Another factor which can be responsible for the higher arthropod abundance during the second experimental period is high weed density, because increased plant diversity results in a multiplicity of ecological niches (Haddad et al., 2009).

The predominance of predator arthropods over the other guilds in the soil interior can be related to prey density and because many of these species use the soil as a place of foraging and breeding. Among the major soil arthropods are the springtails and mites, which typically have higher density in soils with high levels of organic matter and humidity (Fountain and Hopkin, 2005; Lee et al., 2009; Gerlach et al., 2013). These arthropods are important detritivores of plants residues and play a fundamental role in the equilibrium of food webs because they break up large particles of organic matter for other decomposers. Moreover, they serve as alternative prey for some predators (Park and Lee, 2006; Milton and Kaspari, 2007; Paoletti et al., 2007).

Glyphosate application of transgenic soybean decreased the density of predator mites Galumnidae and predator ants *Neivamyrmex* sp. and *Solenopsis* sp. Ants and mites are important

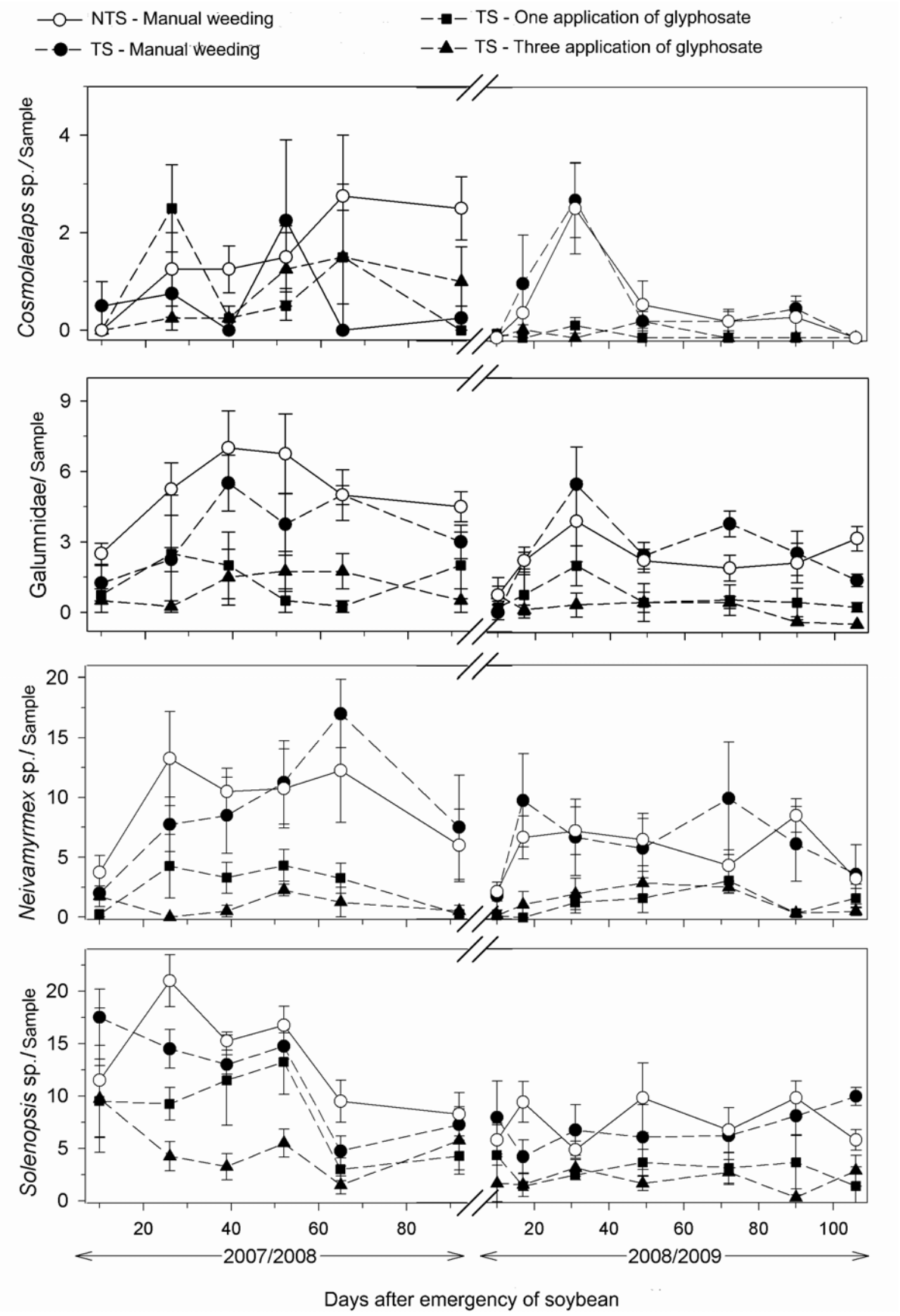

Figure 2 - Abundance (mean ± standard error) of predatory insects from the soil interior in non-transgenic soybean and transgenic soybean with one or three applications of glyphosate. Coimbra, MG, 2007-2009.

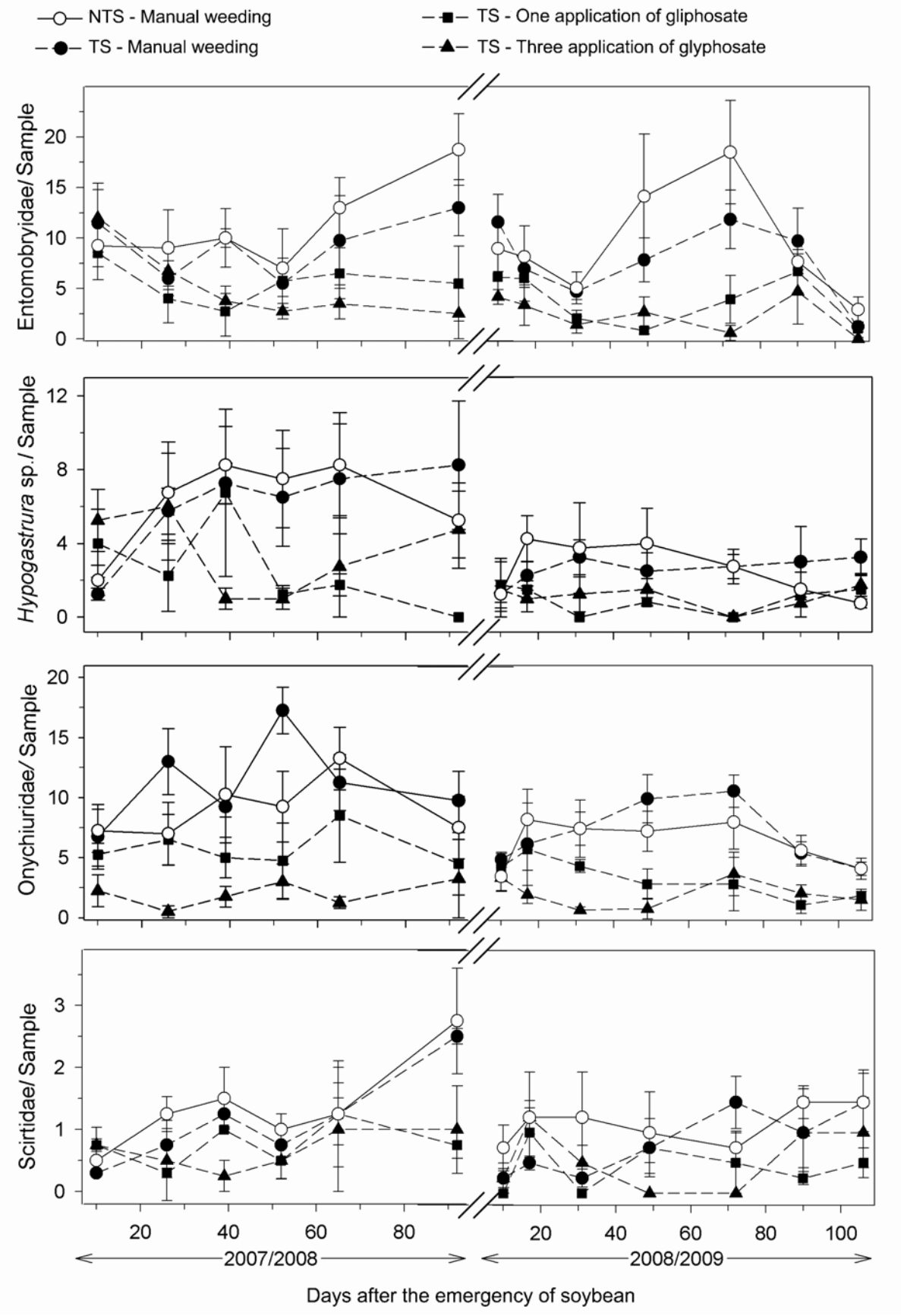

Figure 3 **-** Abundance (mean ± standard error) of soil-detritivore insects in non-transgenic soybean and transgenic soybean with one or three applications of glyphosate. Coimbra, MG, 2007-2009.

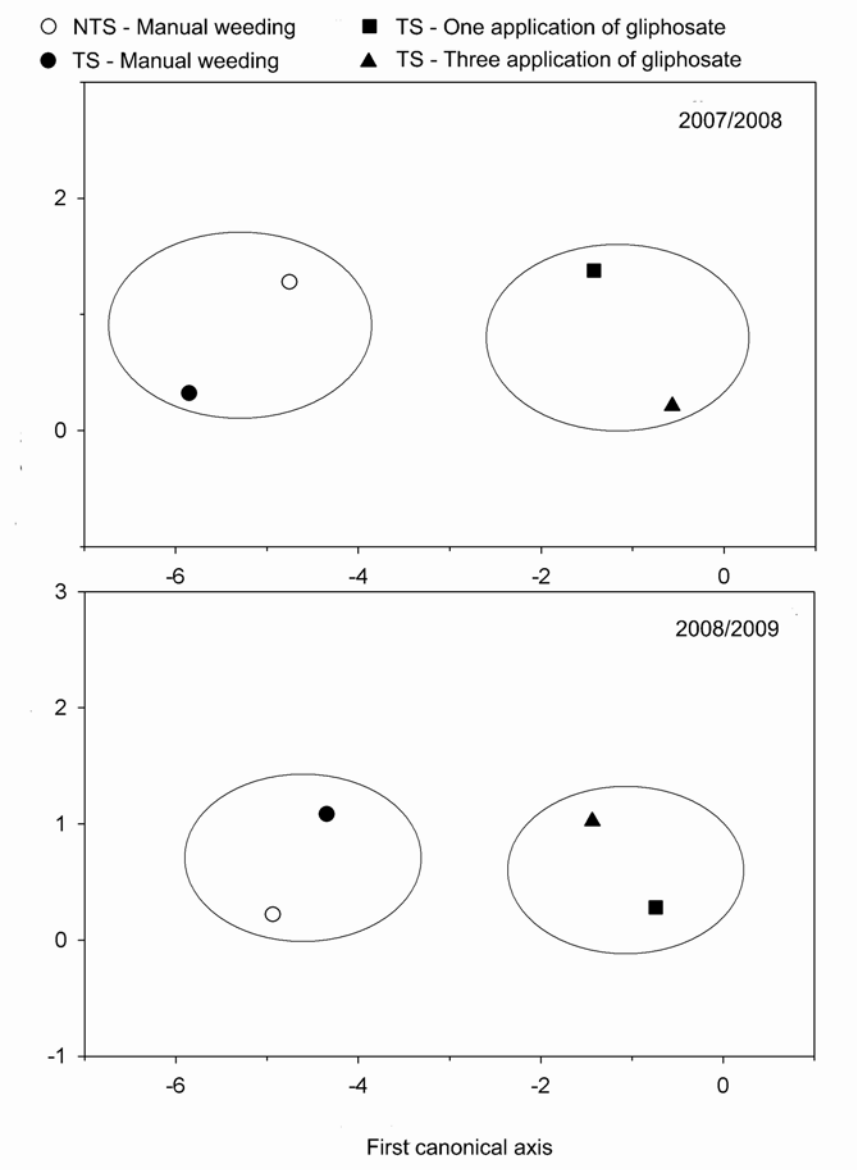

Figure 4 - Ordering diagram (CVA) of the arthropod community in the soil of the soybean crop. Treatments outside the same circle differ by the F test ($p<0.05$), based on the Mahalanobis distance between the means of the classes. Coimbra, MG, 2007-2009.

bioindicators of the soil quality (Pereira et al., 2005; Barbercheck et al., 2009) because they respond rapidly to the changes in the environment and show wide geographic distribution (Pulleman et al., 2012). Mites and ant predator species are generalists, feeding of a large variety of prey. They are important constituents of food webs in various ecosystems, including agroecosystems, where they are biological control agents (Riihimaki et al., 2005). Therefore, the decrease in their densities after glyphosate application can change the food web equilibrium of the agroecosystem.

Glyphosate application of transgenic soybean also decreased the springtails Entomobryidae, *Hypogastrura* sp. and Onychiuridae density. The glyphosate impact on the arthropod community can be because of its molecule toxicity or changes caused by this herbicide on the weed community. The toxicity may be associated with the primary molecule which is a part of this herbicides composition, or derived molecules resulting from its degradation (Parkinson, 2001). Pesticide degradation in the agroecosystem involves reactions of degradation that are capable of generating derivative compounds with different toxicity spectrums in relation to the primary compound. For example, in the soil the pentachloronitrobenzene fungicide (PCNB) is converted

Table 5 - Multivariate analysis by repeated measures of the abundance of arthropods from the interior of the soil in non-transgenic soybean (NTS) and transgenic soybean (TS) with one or three applications of glyphosate (1Gly and 3Gly). Coimbra, MG, 2007-2009

Source of variation	2007/2008			2008/2009		
	Huynh-Feldt	F	P	Huynh-Feldt	F	P
	Cosmolaelaps					
NTS x TS	1.01	1.85	0.267	1.26	0.09	0.785
TS x TS-1Gly	1.14	0.86	0.423	3.60	8.91	0.058
TS x TS-3Gly	1.41	0.02	0.903	2.69	8.80	0.059
Time	1.53	2.02	0.094	0.87	8.03	<0.001
Time x NTS x TS	-	1.44	0.267	-	0.18	0.980
Time x TS x TS-1Gly	-	1.19	0.361	-	4.65	0.005
Time x TS x TS-3 Gly	-	0.87	0.525	-	3.40	0.020
	Galumnidae					
NTS x TS	2.26	1.28	0.340	0.80	0.14	0.731
TS x TS-1Gly	2.43	37.56	0.009	1.33	24.14	0.016
TS x TS-3Gly	3.63	148.41	0.001	1.87	29.62	0.012
Time	1.52	3.95	0.005	0.86	5.45	0.0002
Time x NTS x TS	-	1.11	0.394	-	1.01	0.450
Time x TS x TS-1Gly	-	1.97	0.142	-	1.77	0.162
Time x TS x TS-3 Gly	-	0.73	0.610	-	2.87	0.039
	Neivamyrmex sp.					
NTS x TS	4.02	0.06	0.838	2.65	0.88	0.419
TS x TS-1Gly	4.60	59.18	0.005	1.25	164.68	0.001
TS x TS-3Gly	4.21	35.78	0.009	1.18	52.66	0.005
Time	1.48	2.67	0.034	1.49	41.82	<0.001
Time x NTS x TS	-	0.50	0.769	-	1.07	0.416
Time x TS x TS-1Gly	-	2.22	0.110	-	2.27	0.083
Time x TS x TS-3 Gly	-	2.36	0.090	-	2.64	0.051
	Solenopsis sp.					
NTS x TS	1.05	0.36	0.592	11.39	5.04	0.110
TS x TS-1Gly	2.96	1.33	0.333	1.52	8.34	0.063
TS x TS-3Gly	1.61	41.28	0.008	1.77	16.41	0.027
Time	1.05	6.11	<0.001	1.47	0.39	0.881
Time x NTS x TS	-	0.76	0.595	-	2.26	0.084
Time x TS x TS-1Gly	-	0.43	0.819	-	0.47	0.824
Time x TS x TS-3 Gly	-	1.63	0.212	-	0.66	0.685

in chlorinated benzoic acids, which are toxic compounds to plants (Tas and Pavlostathis, 2014). Therefore, glyphosate herbicide may have undergone this type of biodegradation, and its derivatives may have become toxic to the springtails, as well as species that exhibited a decreased density.

Concerning the changes caused by glyphosate on the weed community, studies have reported that there is a positive correlation between weed density (straw residue) and springtails Hypogastruridae (Pereira et al., 2005). Moreover, the increase of springtails populations promotes the increase of the predator *Solenopsis* sp. density, demonstrating that the presence of alternative prey can favor the increasing of generalist predators, such as ants.

In summary, although transgenic soybean does not affect arthropod richness and abundance in the soil interior, weed management with glyphosate does affect the richness of these organisms. Therefore, when adopting this herbicide, its use should not be made indiscriminately. Product use recommendations, such as recommended dose and reapplication interval, must be

Table 6 - Multivariate analysis of replicate measures of the abundance of soil-dwelling arthropods in non-transgenic soybean (NTS) and transgenic soybeans (TS) with one or three glyphosate applications (1Gly and 3Gly). Coimbra, MG, 2007-2009

Source of variation	2007/2008			2008/2009		
	Huynh-Feldt	F	P	Huynh-Feldt	F	P
	Entomobryidae					
NTS x TS	1.06	0.98	0.394	1.45	3.32	0.166
TS x TS-1Gly	2.38	27.63	0.013	1.33	2.05	0.024
TS x TS-3Gly	3.19	6.14	0.049	1.43	12.09	0.040
Time	1.18	2.07	0.087	1.01	5.03	0.0004
Time x NTS x TS	-	0.30	0.906	-	0.76	0.612
Time x TS x TS-1Gly	-	0.87	0.526	-	0.74	0.626
Time x TS x TS-3 Gly	-	1.46	0.260	-	1.12	0.391
	Hypogastrura sp.					
NTS x TS	1.69	0.15	0.723	1.29	0.01	1.000
TS x TS-1Gly	3.23	15.71	0.029	1.30	24.42	0.016
TS x TS-3Gly	1.56	3.02	0.1808	4.80	7.39	0.073
Time	1.49	0.71	0.615	1.10	0.52	0.788
Time x NTS x TS	-	0.36	0.8693	-	1.38	0.274
Time x TS x TS-1Gly	-	1.89	0.155	-	0.56	0.757
Time x TS x TS-3 Gly	-	1.04	0.433	-	0.36	0.895
	Onychiuridae					
NTS x TS	1.39	0.58	0.502	1.01	1.53	0.231
TS x TS-1Gly	1.12	34.90	0.010	1.07	11.55	0.030
TS x TS-3Gly	1.39	34.27	0.010	0.97	16.62	0.027
Time	1.19	1.23	0.1856	0.99	2.16	0.062
Time x NTS x TS	-	1.81	0.170	-	1.37	0.279
Time x TS x TS-1Gly	-	4.38	0.012	-	0.58	0.744
Time x TS x TS-3 Gly	-	1.40	0.279	-	1.23	0.337
	Scirtidae					
NTS x TS	6.47	1.85	0.267	7.01	4.12	0.135
TS x TS-1Gly	6.70	4.12	0.1354	3.66	3.16	0.174
TS x TS-3Gly	1.40	2.77	0.195	3.31	2.19	0.235
Time	1.51	2.69	0.033	1.49	1.77	0.122
Time x NTS x TS	-	0.06	0.997	-	0.84	0.557
Time x TS x TS-1Gly	-	0.78	0.579	-	1.05	0.425
Time x TS x TS-3 Gly	-	0.62	0.685	-	1.09	0.407

adhered to because they contribute to decreasing glyphosate toxicology potential on natural enemies of the edaphic entomofauna. In addition, good agricultural practices which favor the maintenance of organic matter in the soil should be recommended, since organic matter promotes the edaphic microorganisms responsible for pesticide biodegradation, such as the herbicide glyphosate.

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