Org. Agr. (2016) 6:323–330
DOI 10.1007/s13165-015-0138-y

Long-term effects of alternative and conventional fertilization on macroarthropod community composition: a field study with wheat (*Triticum aestivum* L) cultivated on a ferralsol

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Received: 9 September 2015 / Accepted: 23 October 2015 / Published online: 31 October 2015

Abstract The influence of long-term fertilization on macroarthropod community composition from a field study with wheat (*Triticum aestivum*) was investigated. Soil samples were taken from a long-term field experiment which was conducted for 5 years to explore the effect of three treatments: control (non-fertilization), conventional (mineral fertilizers—NPK), and alternative (organic fertilizers—farmyard manure). The highest values of macroarthropod community composition were found in the alternative fertilization system after the 30 years of its utilization. After 30 years, the conventional fertilization system showed lower values for these studied variables compared to alternative fertilization system. Our findings suggest that inputs of organic matter source can change positively the macroarthropod community composition, and these results highlight the importance of considering the long-term effect of mineral and organic fertilizers on the diversity of this biological component and their effect on wheat growth and soil fertility. Thus, the long-term utilization of an alternative fertilization system with continuous input of organic matter may exploit positive situations of jointly beneficial biotic and abiotic conditions.

Keywords Macroarthropod diversity · Wheat yield · Long-term trial fertilization experiment · Organic fertilizers

Introduction

Understanding the effects of long-term fertilizer utilization that may regulate the macroarthropod community composition from a wheat (*Triticum aestivum* L.) field is essential to explain why the continuous use of mineral fertilizers becomes less beneficial to aboveground and belowground community composition and their interaction with plant development, soil properties, and biodiversity than the use of organic fertilizers in the same conditions (Hole et al. 2005; Zhong et al. 2010). Over time, conventional farming systems may result in a decline of soil organic matter, soil quality, and macroarthropod diversity (Snyder and Hendrix 2008; Gabriel et al. 2010; Drakopoulos et al. 2015), whereas organic farming systems enhance soil fertility and biodiversity with less input of inorganic fertilizers, energy, herbicides, and pesticides (Maeder et al. 2002).

An understanding of macroarthropod community diversity is the key to determine effective farming systems. According to Pfiffner and Luka (2000) and Gabriel et al. (2010), the abundance and diversity of

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soil macroarthropods depend on farming practices (organic vs. conventional systems). Organic farming usually increases macroarthropod richness (average 30 % higher species richness and 50 % higher abundance than conventional farming systems). Usually non-predatory insects and pests respond negatively to organic farming, while predatory insects respond positively (Bengtsson et al. 2005). Macroarthropods contribute to services (e.g., soil fertility) impacting on plant yield in organic farming systems (Pearce and Venier 2006; Gabriel et al. 2010; Mikanová et al. 2013). Macroarthropods actively affect chemical, physical, and biological processes (Lavelle et al. 2006) and believed that they play an important role in nutrient cycling and in the maintenance of good soil quality (Brussaard et al. 1997; Sackett et al. 2010).

In organic systems, many practices improve ecological stability and biodiversity (Lavelle et al. 2006; Barrios-Masias et al. 2011) and reduce environmental degradation (Jackson et al. 2007). So, we hypothesized that the continuous use of organic fertilizers promotes greater positive effects on macroarthropod community diversity (Snyder and Hendrix 2008). Fertilization is recognized as one of the most important practices that influences soil chemical, physical, and biological properties (Mikanová et al. 2013). There are evidences that fertilization can affect diversity and function of soil macroarthropods (Hole et al. 2005). According to Belay et al. (2015), practices like fertilization affects aboveground community, which in turn affects belowground community structure and their function (Bossio et al. 2005). Mikanová et al. (2013) also reported that the long-term fertilization management, like practices with the use of farmyard manure, can improve soil biological activity and fertility, especially by constant input of organic matter.

It may be argued that the long-term utilization of organic fertilizer source could be a viable alternative to enhance macroarthropod diversity in areas from organic wheat producers in the Brazilian Northeast, increasing soil quality and improving wheat yield. In fact, the abundance and diversity of soil macroarthropod can contribute to fundamental services for terrestrial ecosystems, like the decomposition processes (Gabriel et al. 2010). However, there is limited information on how a long-term fertilization may affect macroarthropod diversity in a wheat field. The aim of this study was to determine whether the continuous use of mineral and organic fertilizers influence macroarthropod community diversity. We used the wheat variety, *Triticum aestivum* var. BRS-Guamirim, which is a highly cultivated wheat variety, particularly in the Southeastern Brazil. We investigated whether the influence of fertilization systems (alternative and conventional) on above- and belowground community composition in a wheat field cultivated on a ferralsol changed macroarthropod diversity after 5 years of continuous use of mineral and organic fertilizers.

Materials and methods

Studied site

The long-term field experiment was carried out at the “Chã-de-Jardim” Experimental Station, Agrarian Science Centre, Federal University of Paraíba (CCA-UFPB), located in Areia, Paraíba, Brazil (06° 58′ 12″ S, 35° 42′ 15″ W, altitude 619 m). The climate in the area is As’ (Köppen), with average annual precipitation and temperature of 1500 mm and 21 °C, respectively. Data on the climatic condition of the investigated area from January 2007 to December 2011 were obtained from the website: http://www.inmet.gov.br. In particular, for downtown Areia, Paraíba, Brazil, monthly rainfall and main temperature were considered and reported (Fig. 1).

The soil examined was classified as a ferralsol (WRB 2006). Soils were collected at the beginning of March of each studied year during the dry period and when the plants were in heading growth stage. Soil samples were collected from a depth of 0–20 cm, air-dried and passed through a 2-mm sieve. Soil pH was determined in a suspension of soil and distilled water (Black 1965). Soil organic carbon was estimated according to the methodology described by Okalebo et al. (1993). Total soil nitrogen content was estimated using the Kjeldahl method (Black 1965). Available phosphorus (Olsen’s P) was determined colorimetrically on spectrophotometer at 882 nm by extraction with sodium bicarbonate for 30 min (Olsen et al. 1954). The chemical characteristics of the soil site before to start the experiment are given in Table 1.

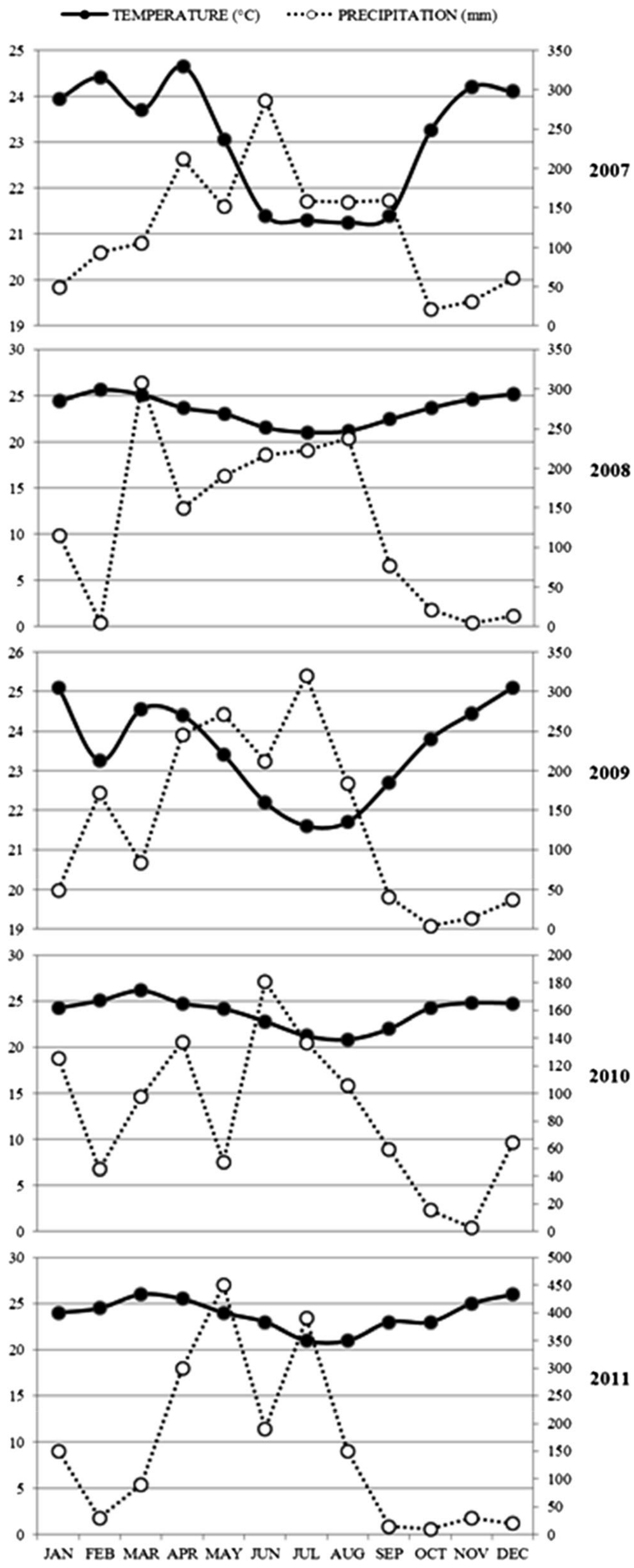

Fig. 1 Mean temperature (*black line*) and rainfall amount (*dotted line*) in the studied site near to downtown Areia, Paraíba, Brazil from January 2007 to December 2011; data were obtained from the website: http://www.inmet.gov.br

Table 1 Soil chemical characteristics (0-20 cm) before to start the experiment and macroarthropods collection

pH (1:2.5 soil:H_2O)	Total organic *C* (%)	Total *N* (%)	Available *P* (mg dm^{-3})
4.28	0.73	0.19	4.29

We performed a long-term study in this area during 5 years (2007–2011). Thus, we used an area of 72 × 36 m which was under grasses for about 10 years, where signalgrass (*Brachiaria decumbens* Stapf.) was the dominant grass species before to start the experiment.

Experimental setup and design

Three treatments were allocated in a randomized block design that consisted of three fertilization systems: (1) control—no fertilization; (2) conventional system—NPK fertilization according EMBRAPA's recommendation for *Triticum aestivum* cv. BRS—Guamirim L. tillage; and (3) alternative system—organic fertilization according to regional familiar agriculture sustainable system (See more details about fertilizers, doses, and application mode in Table 2). Each treatment plot (10 × 10 m) was replicated in six blocks, and for our analysis, we used the central portion (5 × 5 m) of each plot.

Harvest yield

After 140 days of planting, the wheat was harvested. Plants were harvested from each plot at 8–10 cm above the ground level and threshed through power-operated thresher and grain yield was recorded. We used the grain yield data to estimate the harvest yield in kilograms per hectare (kg/ha). The harvest yields (kg/ha) of the specific trials are given in Fig. 2.

Macroarthropod analysis

The Tropical Soil Biology and Fertility (TSBF) protocol, described by Anderson and Ingram (1989), was used to sample the soil macrofauna. Sampling was carried out at the same sites in the same way when the plants were starting flowering (September/October). Samplings were performed at each plot of the experiment area, totaling 12 sampling points per year. A 0.25 × 0.25 m area was delimited at each

Table 2 Experimental setup, fertilizers, doses, and fertilization application mode during the 5 years of the study

Activities[a]	Control	Conventional	Alternative
Soil prepare (traction)	Yes (animal)	Yes (mechanical)	Yes (animal)
Liming[b]	No	Yes—1.2 T ha^{-1}	Yes—1.2 T ha^{-1}
Mode of application	-	Limestone was incorporated 4 months before planting	
Fertilization	No	Yes—mineral	Yes—organic
Fertilizer (doses)	-	Ammonium sulfate (30 kg N ha^{-1}) Triple superphosphate (70 kg P_2O_5 ha^{-1}) Potassium chloride (60 kg K_2O ha^{-1})	Farmyard manure (20 T ha^{-1})
Mode of application	-	Incorporated during planting	Incorporated 2 months before planting
Seed density	300 seeds/m^2		
Distance between crop lines	17 cm		
Top dressing	No	Yes—N fertilization	No
Fertilizer (doses)	-	Urea (30 kg N ha^{-1})	-
Mode of application	-	Incorporated besides crop lines 30 days after planting	-
After care	Yes—manual control of invasive herbs	Yes—chemical control of invasive herbs (glyphosate 2 L ha^{-1})	Yes—manual control of invasive herbs

[a] These activities were performed during the 5 years of the study

[b] Liming was used two times, during the first year (2007) and in the last year (2011)

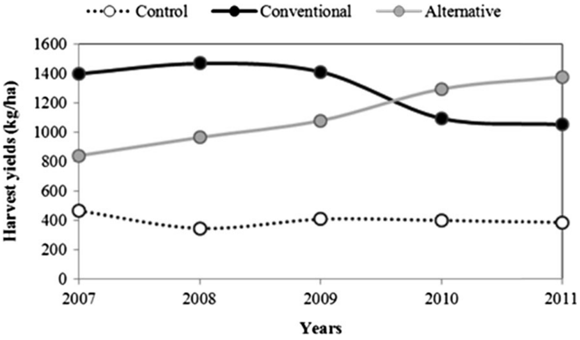

Fig. 2 Harvest yield of wheat plants grown under three different fertilization systems (conventional fertilization (*black line*), alternative fertilization (*gray line*), and control (*dotted line*)) during the 5 years of the experiment

point, and layers of plant material and soil were sampled down to a depth of 0.2 m.

The macroarthropod individuals longer than 10 mm were removed manually and stored in containers with 70 % alcohol. These were later counted and identified under a stereoscopic microscope, at the level of major taxonomic group. The term group was used in the soil macroarthropod study, meaning either a family, a class, or an order, with the objective of comprising a set of individuals with a similar life form. The communities were characterized based on the following parameters: (a) density, number of individuals per square meter; (b) Shannon Diversity Index (H) (Shanon and Weaver 1949); and (c) Simpson dominance index (C) (Simpson 1949). In addition, we assessed the order occurrence frequency of every macroarthropod orders by each studied treatment. The macroarthropod community composition observed during the experiment is given in Table 3.

Statistical analysis of data

The main effect of fertilization systems, studied year (years of fertilization uses), and their interaction were tested by means of a two-way ANOVA. Data sets not meeting assumption for ANOVA were transformed as required (arcsin square root for percentage variables and logarithmic for other variables), but the results were presented in their original scale of measurement (means with standard deviation) (Zar 1984). Mean separation was conducted based on Tukey's multiple range tests. Differences at $p<0.05$ were considered statistically significant. Two-way ANOVA, Pearson correlation coefficient, and Tukey's multiple range tests were conducted using SAS 9.1.3 Portable.

Results and discussion

The two-way ANOVA showed a significant effect of the fertilization system utilization on the Shannon's index

Table 3 Macroarthropod frequency of occurrence by each studied treatment. *FO* (%) observed in fertilization systems (control, conventional, and alternative fertilization) and years of their use (2007, 2008, 2009, 2010, and 2011)

Orders	Control (non-fertilization)					Conventional fertilization					Alternative fertilization				
	2007 *FO*[a]	2008	2009	2010	2011	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
Araneae	2.8	0	0	0	0	1.8	0.6	0	0	0	2.6	1.5	3.2	4.1	4.7
Larvae of Coleoptera	1.5	1.9	2.2	0	0	1.8	2.3	4.3	4.3	4.2	1.7	2.3	3.2	3.3	2.3
Coleoptera	3.8	3.8	2.8	2.3	2.7	5.3	3.0	2.6	2.5	2.1	2.6	1.5	2.4	1.6	2.3
Hymenoptera	76.5	84.9	83.9	84.0	82.3	64	57.8	57.4	55.2	53.2	68.7	61.8	63.4	64.8	62.6
Orthoptera	0.8	0.6	1.1	0.6	1.1	0.8	1.2	1.7	0.7	1.1	0.9	1.5	0.8	1.6	1.6
Mantodea	0.8	0	0	0	0	0.8	0	0	0	0	0.9	0.8	1.6	0.8	1.5
Larvae of Diptera	1.5	0.6	1.1	1.2	0	2.6	2.3	1.3	0.7	0.7	0.9	0.8	0.8	0	0
Blatodea	0.8	1.3	0.6	0.6	0	0.9	0	0	0	0	0.9	2.3	1.6	2.5	3.9
Isoptera	9.0	5.7	7.2	8.5	8.6	20.2	31.6	31.8	35.5	35.5	17.4	24.4	21.4	20.5	20.3
Homoptera	1.0	0.6	0	0	0	0.9	0.6	0	0	0	1.7	2.3	0.8	0.8	0.8
Hemiptera	1.5	0.6	1.1	2.8	5.3	0.9	0.6	0.9	1.1	3.2	1.7	0.8	0.8	0	0

[a] $FO_i=n_i/N$, where n_i is the number of times an individual of a species was observed and N is the total of species observed from each studied treatment

($F_{2,\ 45}$=53.01, p<0.001) and Simpson's index ($F_{2,\ 45}$= 89.58, p<0.001) during our study. The other factor considered in these analyses (studied years) did not have any significant effect on these variables. This study shows that the continuous use of fertilization systems changes the macroarthropod community. Non-fertilization treatment (control) did not benefit any variable in our study. The results from macroarthropod community indicated that the alternative fertilization use had positive effects on the composition of this component, especially for the number of individuals per square meter.

The HSD Tukey's test revealed that there was no difference between the use of conventional and alternative systems on Shannon's (Fig. 3a) and Simpson's index (Fig. 3b), but these treatments had significant higher values when compared with the values observed in the control. We cannot exclude the hypothesis that a practice of soil management that encourages the input of organic carbon may be also involved in the shift from negative to neutral in the macroarthropod community, which can be supported by the results in the alternative fertilization continuous use on Shannon and Simpson index and number of macroarthropods per square meter (Fig. 3a, b). These results agree with the work done by Silva et al. (2006) that reported higher abundance of macroarthropods in preserved areas than in intensive soil management. This result may be associated with the higher amount of plant residues in the alternative fertilization systems.

The number of macroarthropods per square meter in all treatments from the first studied year was about 2000 ind m^{-2}, which we did not find any difference in between this variable. The two-way ANOVA showed a significant effect of the fertilization systems ($F_{2,\ 45}$= 56.50, p<0.001), the studied years ($F_{4,\ 45}$=62.74, p<0.001), and the interaction between these two factor ($F_{8,\ 45}$=26.80, p<0.01) on this variable. In conventional fertilization, this variable was significantly improved after the first year from values of 1824 to 4544 ind m^{-2}. The same comportment was observed for this variable under control treatment that had its number of macroarthropods increased from 2112 to 2992. For the alternative fertilization, we only observed a significant positive effect on this variable between the first and the second year; after it, we did not find any effect of this treatment on the number of macroarthropods (Fig. 3c).

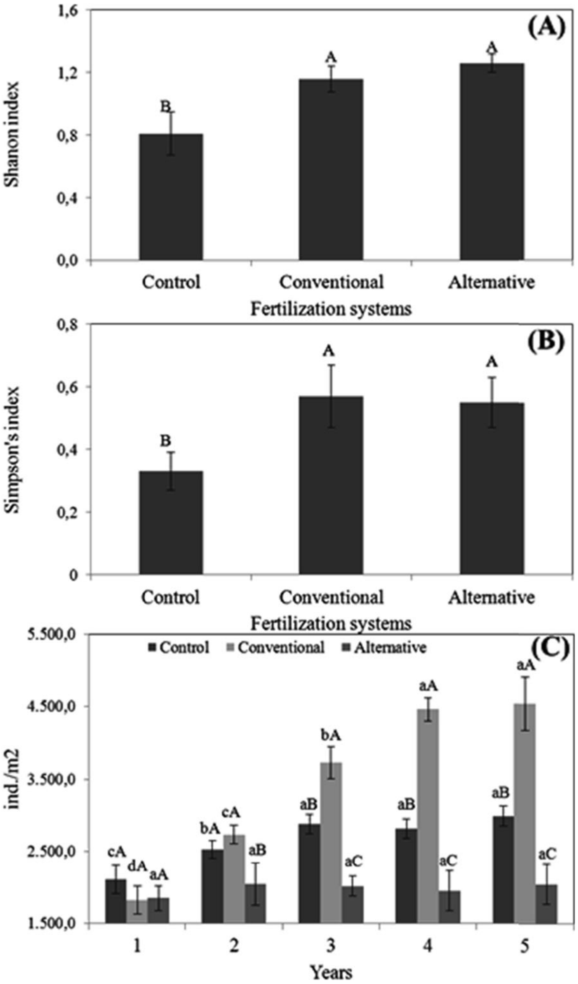

Fig. 3 Effects of different fertilization systems (control, conventional, and alternative) on Shannon's (Fig. 3a) and Simpson's (Fig. 3b) macroarthropod community; and the effects of different fertilization systems and years of their utilization on number of macroarthropods (ind m^{-2}, Fig. 3c) (means±SD). Within fertilization systems into Fig. 3a, b, means with different capital letters are significantly different by HSD test at the 5 % significance level. For Fig. 3c within fertilization systems, means with different capital letters are significantly different by LSD test at the 5 % significance level. Within each studied years, means with different lowercase letters are significantly different by LSD test at the 5 % significance level

Plant residues are important to this group of organisms and act as food resource and refuge site to macroarthropods (Costa et al. 2009; Pearce and Venier 2006). Macroarthropods, especially orders with greater abundance, are widely used to assess the conservation status of ecosystems (Luz et al. 2013). Among the orders that we observed in our study, the most frequent orders were Hymenoptera and Isoptera for all studied treatments. The first one, especially in the control (non-fertilization treatment), and the second one are more frequent in the conventional fertilization. Among the Hymenoptera, the family Formicidae were predominant in the control and conventional fertilization. For the alternative fertilization, we found three different families of the order Hymenoptera: Apidae, Formicidae, and Multilidae, but with Formicidae as a dominant group.

Our results agree with the works done by Wink et al. (2005) that found Formicidae as a dominant group in different ecosystems and habitats and Luz et al. (2013) that reported higher diversity of ants in habitats with high organic matter contents than disturbed habitats. Among the order Coleoptera, the most frequent families were Carabidae and Scarabaeidae, but the second one only was found in the alternative fertilization. Our results agree with the work done by Luz et al. (2013) that reported Scarabaeidae in preserved areas. Beetles of this family are very sensitive to changes in habitat, especially soil organic carbon (Costa et al. 2009; Azevedo et al. 2011). Predators such as Araneae and Mantodea were only found in the continuous use of the alternative fertilization. For the control and conventional fertilization treatments, these orders only occur in the first year of our study. For the conventional fertilization, the release of beneficial macroarthropods was probably more significant, since after its continuous use, there was an increase in number of individuals (Fig. 2c) from order Hymenoptera, family Formicidae, and a decrease in the number of individuals from order Araneae, Mantodea, and Hymenoptera. Generally, predators are related to more diverse habitats, with a depth layer of litter that provides hunting and foraging niches and for protection from desiccation (Pearce and Venier 2006). This explains their presence in the alternative fertilization (Table 2).

Although our experiment was not designed to directly test whether fertilization systems affect wheat growth through changes in soil nutrient availability, the changes in soil organism diversity that we observed may be related to alterations in soil nutrient resources after the continuous use of both fertilization, alternative and conventional. Nevertheless, the fertilization systems are even likely to directly affect soil organism communities. Which groups of soil organisms may be most affected is not known, and this can vary depending on the severity of environmental conditions (Neary et al. 1999).

Conclusion

In conclusion, the alternative fertilization system changed positively the macroarthropod community composition, especially the richness and abundance of predatory insects in the wheat field cultivated on a ferralsol during 5 years of its utilization. The use of farmyard manure promoted positive effects whereas the use of mineral fertilizer promoted negative on all studied variables in our study. So, our findings suggest that inputs of organic matter promoted by organic farming had positive effects on macroarthropod community composition and harvested yield. The results of our study highlight the importance of considering the long-term effect of alternative fertilizations systems, based on organic farming without use of pesticides, herbicides, and inorganic fertilizers. Thus, the long-term utilization of an alternative fertilization system with continuous input of organic matter may exploit positive situations of jointly beneficial biotic and abiotic conditions.

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