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Soil invertebrates in durum wheat (*Triticum durum* L.) cropping system under Mediterranean semi arid conditions: A comparison between conventional and no-tillage management

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ABSTRACT

One of the challenges of research in soil ecology is to assess the impact of tillage managements on soil invertebrates. It is known that tillage practices change soil water content, temperature, the degree of mixing of crop residues within the soil matrix and the physico-chemical environment for soil organisms. The present study tested whether no-tillage (NT) or a conventional tillage (CT) of a cereal (durum wheat; *Triticum durum*) field in a semi-arid zone of northwestern Tunisia could improve the biological activity and diversity of soil invertebrates, especially arthropod and earthworm communities.

The experiment was conducted in January 2000 at two different sites (Mahasse/Kef Governorate and Krib/Siliana Governorate). Soils (Brunisols, isohumic or fersialitic soil) were silt/clay in Mahessen and sand/clay in Krib. After three and four years, soil fauna was sampled with two methods (quadrat and pitfall trap) over 7 months for the last two growing seasons (2002/2003 and 2003/2004). We hypothesized that: (i) soil fauna richness, abundance and diversity would be lower in CT soils than in NT soils and (ii) the move from CT to NT may improve the soil biological component under semi arid conditions.

380 invertebrates (37 species) and 309 invertebrates (24 species) were collected by quadrat and pitfall trap methods, respectively. NT greatly enhanced the species richness (from 26 species in CT to 34 species in NT) and abundance (from 61 individuals in CT to 319 individuals in NT) of soil invertebrates with quadrat method. Only abundance was significantly enhanced with pitfall trap method (from 78 individuals in CT to 235 individuals in NT). So, abundance, species richness and diversity of soil arthropods were significantly higher ($P < 0.05$) with NT than with CT. Soil fauna patterns showed that management mode affected also the abundance of earthworm community. These findings confirm our first hypothesis.

Predators (mostly *Carabidae*), detritivore (especially: *Formicidae*, *Dolicoderidae*, *Lumbricidae*) and herbivore (represented here by *Julidae*, *Pyrrhochridae* and some *Scarabaeidae*) were significantly ($P < 0.05$) more abundant with NT than with CT. The biological index *V* (index which compares the relative increase or decrease of the population density between the two tillage modes) showed that all major taxonomic groups were extremely inhibited by CT, confirming our second hypothesis.

So, NT seems to be beneficial to biological soil component where it favoured the establishment of diverse soil communities than did CT in durum wheat cropped field. Furthermore, soil fauna may enhance crop-residues decay processes.

1. Introduction

Recently, in Mediterranean areas, there is an increasing interest in new soil conservation management practices such as minimum or no-tillage systems. With the intensification of arable land use over the last decade, essentially, in semi arid areas, depletion of soil fertility has emerged as a major issue. Therefore, there is a need for sustainable farming systems with practices such as conservation agriculture that aim to maintain soil structure and improve fertility (Pfiffner and Luka, 2007). Indeed, conservation agriculture (CA), defined as minimal soil disturbance (no-till) and permanent soil cover (mulch cover crop) combined with rotations, is a more sustainable cultivation system for the future. Conservative tillage is the collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage to denote that the specific practice has somehow a conservation goal. Usually, a 30% surface cover by residues characterizes the lower limit of

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requirement for conservation-tillage, while benefits are on time, fuel, earthworms, soil water, soil structure and nutrients (Baker et al., 2002).

No-tillage (NT) is widely recognized by scientists and agronomists as a viable alternative to conventional tillage (CT) to get healthy soil and sustain natural resources. This Ag-technology methodology is used worldwide on over 100 million hectares (Lal et al., 2007). Such tillage system leaves organic mulch on the soil surface, which reduces runoff, increases soil organic matter and improves aggregate stability, thereby limiting soil erosion (Franzluebbers, 2002). Soils under NT generally contain more organic matter, organic C, organic N and microbial biomass than soils under CT (Chivenge et al., 2007; Thomas et al., 2007; Ben Moussa-Machraoui et al., 2010), while the soil management system has been shown to rebuild soil fertility (Ito et al., 2006).

Invertebrates enhance mixing, macroporosity, humidification and mineralization of soil organic matter (Francis and Fraser, 1998). These processes improve structure, texture, water retention, and chemical and nutritional properties of soil (Lal, 1988; Kladivko, 2001; Ouedraogo et al., 2006).

There is some evidence that NT practices can increase soil invertebrate populations which are substantially influenced by changes in their habitats mainly soil structure and soil organic matter content. Moreover, it is well known that tillage has a high impact on soil structure and subsequently affects arthropod and earthworm communities (Capowiez et al., 2009).

In NT systems, crop residues left on the surface keep the soil cool and moist, improve its structure and serve as a feed for soil fauna (House and Parmelee, 1985; Wardle, 1995; Chan, 2001). Crop residues generate a more complex biological system and stable microclimatic conditions relative to soil humidity and temperature, making a better habitat for soil fauna (Stinner et al., 1988; Winter et al., 1990). Absence of biomass flora is one of the main ways of modifying animal habitats. For example, arthropods are sensitive to changes in biomass and their role is important in the agro-ecosystem. They are partly responsible for detritus degradation and organic matter cycling, making available the nutrients required by other organisms (Giesy et al., 2000).

Earthworms are a major component of many terrestrial ecosystems (Lee, 1985; Edwards and Bohlen, 1995). In several soils, they dominate the biomass of soil invertebrates and function as ecosystem engineers by structuring the environment of the organic matter and/or residues decomposer community (Lavelle et al., 1997). They can affect the density and distribution of other soil invertebrates and modify microbial activity (Brown, 1995; Kladivko, 2001). Earthworms' response to tillage practices and their impact on nutrient cycling and microbial interaction were reviewed in several books, (Hendrix, 1995; Edwards, 1998).

Several reasons led to the adoption of no-tillage in Tunisia: Tunisian agriculture is subject to an arid to semi-arid climate. Agricultural lands are threatened by water erosion which, over the years, has caused enormous losses of soils and the deterioration of soil quality. Cultivation methods based on mechanization have also worsened the situation (Ben Salem et al., 2006). Semi-arid is characterized by erratic rainfall and precipitation appearance. Absence of vegetation cover on the soil plowed, let on soil plowed, let these soils exposed to downside risks related to the effects of runoff and erosion. The climatic and soil conditions and socio-economic conditions promote the dynamics of erosion responsible for physical, chemical and biological deterioration of soil (Ben Hammouda et al., 2004). Cultivation of fragile soils, combined with high-intensity autumn rainfall, leads to severe erosion and declining productivity.

NT was introduced in 1999 to the rainfed agricultural areas of Tunisia to determine if cropping systems based on cereal crops [durum wheat (*Triticum durum*), barley (*Hordeum vulgare*), and oat (*Avena sativa*)] could be sustainable and productive. Ever since, more land (51 ha in 1999 vs. 2900 ha in 2005) has been cropped using NT (Richard, 2007). While the use of NT is increasing in Tunisia, a little is known on its effects on soil characteristics and crop yield, especially in the semi-arid zone (Ben Hammouda et al., 2004; Ben Salem et al., 2006; Richard, 2007; Ben Moussa-Machraoui et al., 2010). However, its impact on soil invertebrate communities, particularly on arthropods and earthworms population, is still unknown.

The objective of this study, was to compare the impacts of both no-tillage and conventional tillage on abundance, density and taxonomic diversity of soil fauna in a durum wheat field located in the semi-arid areas of the north-west Tunisia. Results may lead towards an alternative management system to conventional tillage in the Mediterranean semi-arid areas of Tunisia. We hypothesize that the move from CT to NT could enhance the abundance and the diversity of Brunisols fauna and improve the soil biological component under semi-arid conditions in north-west Tunisia.

2. Materials and methods

2.1. Sites description

The study was carried out at 2 sites in a semi-arid zone in the north-west of Tunisia, characterized by a cold and/or temperate winter, over four (2000–2001, 2001–2002, 2002–2003, and 2003–2004) growing seasons. The first site was in Mahassen (Kef-Governorate; 36°15′44′N; 8°48′33′E; altitude = 580 m) and the second was in Krib (Siliana-Governorate; 36°22′24″N; 9°10′26″E; altitude = 460 m) (Fig. 1). Soils (Brunisols isohumic or fersialitic soil; Girard et al., 2005) were silt/clay, basic pH in Mahassen and sand/clay, basic pH in Krib. Average of total annual precipitations is higher at Krib (727.0 mm) than at Mahassen (574.7 mm), without statistical significance ($P > 0.05$). These values are slightly high compared to that expected in the semi-arid areas because of the quantity of rain which fell in 2003 and in 2004 which is higher than the normal. However, mean monthly precipitations in the two sites were similar, with a minimum in July–August and a maximum in November–December at both sites (Fig. 2A). The annual mean temperature was ≈1.5 °C higher in Mahassen (18.9 °C) than in Krib (17.6 °C), without significant differences ($P > 0.05$) and mean monthly temperatures were similar, with a maximum in July–August and a minimum in December–January (Fig. 2B).

2.2. Tillage management and sampling of soil fauna

Prior to any experimentation, the 2 sites were under CT (mouldboard ploughing down to 0.20–0.25 m). Under NT treatment, soil was opened just to place seeds at the appropriate depth using a specific drill, while residues were left on soil surface. In both sites, durum-wheat was cropped under CT and NT. These two tillage systems have been applied since 1999, in a durum-wheat/durum-wheat rotation at Krib and a durum-wheat/barley rotation at Mahassen. From each site (Mahassen, Krib), two experimental and adjacent plots of a larger trial (Ben Moussa-Machraoui et al., 2010) were used: one for CT and one for NT, with ≈5000 m^2, 6500 m^2, respectively, for Mahassen and Krib. Though both sites were under CT/NT experimentation for 5 years (1999–2004), soil fauna sampling is relevant only to the last 2 growing seasons (2002–2003 and 2003–2004) for which two methods were used:

(i) invertebrates were collected 7 times on a regular date interval from December (2002) to June (2003) at Mahassen and from January (2003) to July (2003) at Krib using the quadrat method. This experiment was replicated in the following growing season (2003–2004). From each plot, 1 sample corresponded to

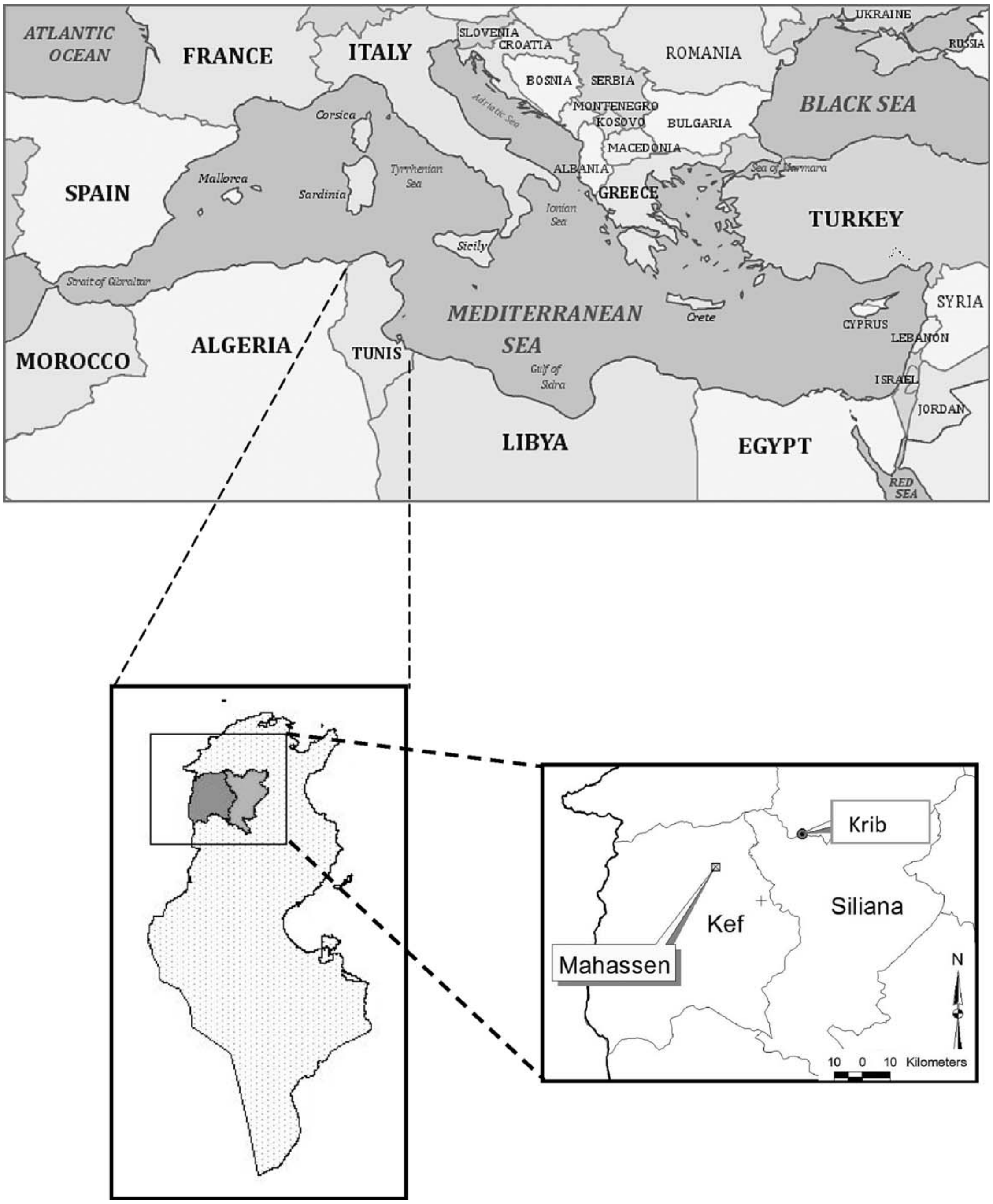

Fig. 1. Location of experimental sites.

4 continuous quadrats arranged in a square and spaced 20 m apart. Each quadrat has 2500 cm^2 of area and 20 cm of soil depth and litter. Extracted fauna from each plot concerned population density for 1 m^2. Captured species at the seven dates of each plot were recorded and pooled, making one sample unit. In the laboratory, invertebrates were identified to the species level. For ants, only the number of species was assessed because of the higher number of individuals per anthill, and the density of these populations was not used in the statistical analysis;

(ii) in 2004, a parallel temporal survey of soil invertebrates, using pitfall traps, was made on 7 dates from January to July 2004. 4 pitfall traps spaced 20 m apart were placed in the center of each plot to avoid border effects. Each trap consisted of a (6.5 cm $\times$ 9 cm) white cup containing water and detergent as a preservative. For each date, pooled species from the 4 traps at the same plot were considered as a single unit. A total of 112 pitfall traps (4 $\times$ 2 plots $\times$ 2 sites $\times$ 7 months) were placed in the field during the experiment. After each sampling period, the content of each trap was carried out to the laboratory for species identification.

2.3. Data analysis

2.3.1. Calculated indices

Out of the data, the following calculations were made: density/m^2, species richness (the number of species), the diversity Shannon–Weaver (H') and Margalef (D) indexes, the evenness

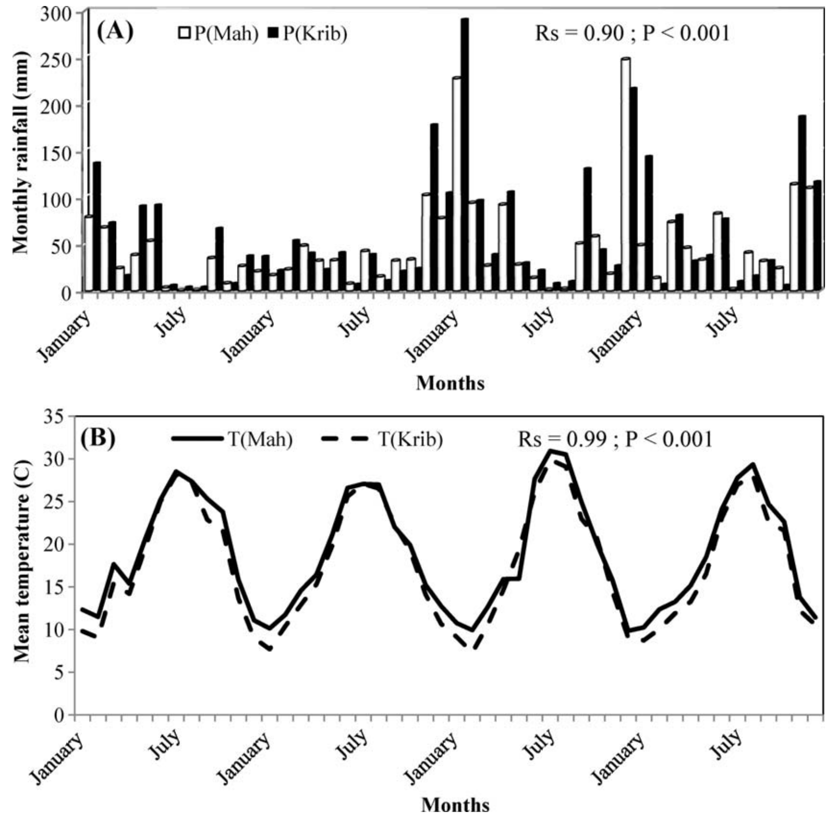

Fig. 2. Monthly precipitations (A) and temperatures (B) at Mahassen (Mah) and Krib (four years; 2001–2004). Rs, Spearman rank correlation between Mahassen and Krib data sets. Mahassen: 18.6 °C mean; 574.7 mm mean annual and Krib: 17.1 °C mean; 727.0 mm mean annual.

(Pilou index, E) (Daget, 1976) and the index of change V (Wardle, 1995).

The Shannon–Weaver index was calculated by the following formula:

$$H' = -p_i \sum \log_2 p_i$$

where p_i is the proportion of the i-specie to the total number of species in each sample. $H_0 = 0$ when there is only one species constituting the assemblage and its value reaches the maximum when all species are of equal abundance.

The evenness index corresponds to the ratio between the H' and the theoretical maximum diversity. It was calculated as follows:

$$E = \frac{H'}{\log_2 S}$$

where S is the number of species. E tends to 0 when few species dominate the assemblage and reach 1 when all species have equal density.

The Margalef index was calculated as follows:

$$D = \frac{S-1}{\log N}$$

where S is the number of species and N is the total number of individuals.

Finally, to compare the relative increase or decrease in organism density between CT and NT, the index of change V (Wardle, 1995) was calculated for the most abundant organism group. The index V was calculated as follows:

$$V = \left(\frac{2M_{CT}}{M_{CT} + M_{NT}}\right) - 1$$

where M_{CT} and M_{NT} are the densities of organisms under CT and NT, respectively. The index V ranged from -1 (organism occur only in NT) to +1 (organisms occur only in CT). 0 represents equal densities. Wardle (1995) considered that there were

extreme inhibition by tillage if $V < -0.67$;
moderate inhibition by tillage if $-0.67 < V < -0.33$;
mild inhibition by tillage if $-0.33 < V < 0$;
mild stimulation by tillage if $0 < V < 0.33$;
moderate stimulation by tillage if $0.33 < V < 0.67$; and
extreme stimulation by tillage if $V > 0.67$.

2.3.2. Statistical analysis

In order to assess the effect of tillage system on the density of soil invertebrate populations, and to identify site and/or year effects, data were submitted to a multifactor analysis of variance (ANOVA).

Multivariate analyses were carried out to check the affinities between species, tillage system, sites and years. Data from quadrat experiment were $\log(x + 1)$ transformed and a correspondence analysis (CA) was plotted for the 2 sites.

Chi-square and Student's tests were applied for an eventual significant difference between the two tillage systems. The Spearman rank correlation (Rs) test was used to study an eventual correlation between climatic factors.

All statistical analyses were performed with Statistica 6 and Primer 5 software.

3. Results

3.1. Quadrat method sampling

A total of 380 invertebrates were captured during 2002–2004 period, representing 37 species, 29 families, 14 orders, 4 classes and 2 phyla (Table 1). Phylum of Arthropoda animals was the most abundant, and Insecta class too, with a ratio of 31/37, and 75.8% of

Table 1
Abundance of soil fauna (density/m^2) as a function of soil management system (CT vs. NT) and the two experimental sites (Mahassen and Krib). Soil fauna was sampled by extracting 4 quadrats of 50 cm × 50 cm (in area) × 20 cm (in depth) soil. Species were captured during the 2002–2003 and 2003–2004 durum wheat growing seasons. Each value corresponds to the pooled data from 7 dates (7 captured months). CT, conventional tillage; NT, no-tillage. For Hymenoptera A = anthill.

Taxa	Order	Family	Species	Abb.	Mahassen				Krib				Total	
					2002–2003		2003–2004		2002–2003		2003–2004		2002–2004	
					NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
Insecta	Coleoptera	Geotrupidae	*Geotrupes stercorarius* (Linnaeus, 1758)	Gst	2	1	2		5		1	3	10	4
		Scaarabaeidae	*Onthophagus ovatus* (Linnaeus, 1767)	Oov	4	5			17			5	21	10
		Melolonthidae	*Amphimallon solstitialis* (Linnaeus, 1758)	Aso	2		4		5	1	3	2	14	3
		Staphylinidae	*Ocypus olens* (Müller, 1764)	Ool		1	1	2		1	1		2	4
			Ocypus brunnipes (Fabricius, 1781)	Obr		1						1		2
		Silphidae	*Phosphuga atrata* (Linnaeus, 1758)	Pat						1				1
		Chrysomelidae	*Chrysochus auratus* (Fabricius, 1775)	Cau	1				6			1	7	1
			Bruchus pisorum (Linnaeus, 1758)	Bpi			1			2			1	2
		Curcilionidae	*Calandra granaria* Linnaeus, 1758	Cgr							1		1	
		Meloidae	*Meloe proscarabacus* (Linnaeus, 1758)	Mpr								1		1
		Carabidae	*Carabus glabratus* Paykull, 1790	Cgl		1	2		8		1		11	1
			Agonum placidum (Say, 1823)	Apl			2						2	
			Tomoxia bucephala (Costa, 1854)	Tbu	5	2	2	2	3	1	1	4	11	9
			Pterostichus madidus (Fabricius, 1775)	Pma					1				1	
			Dromius agilis (Fabricius, 1787)	Dag	1				1		1	1	3	1
		Aphodiidae	*Calamosternus granarius* (Linnaeus, 1767)	Cgs	1		2	1	1		1		5	1
		Elatridae	*Agriotes spitator* (Linnaeus, 1758)	Asp				1			1		1	1
		Coccinellidae	*Coccinella septempunctata* (Linnaeus 1758)	Cse	1		1	1					2	1
	Diptera	Drosophilidae	*Drosophila melanogaster* (Meigen, 1830)	Dme		2			1				1	2
	Hymenoptera	Formicidae	*Formica rufa* (Linnaeus, 1761)	Fru	1A	2A	2A	2A	2A		1A		6A	4A
			Lasius fuliginosus (Latreille, 1798)	Lfu		2A	3A	2A			1A		4A	4A
			Messor barbarus (Linnaeus, 1767)	Mba	2A	1A							2A	1A
		Dolicoderidae	*Iridromyrmex humilis* (Mayr, 1868)	Ihu		1A	2A		3A		1A		6A	1A
	Dermaptera	Forficulidae	*Forficula auricularia* (Linnaeus, 1758)	Fau					5		2	2	7	2
	Orthoptera	Gryllidae	*Gryllus bimaculatus* (De Geer, 1773)	Gbi			1						1	
	Dictyoptera	Blattidae	*Blatta orientalis* (Linnaeus, 1758)	Bor	40		1						41	
		Blatellidae	*Ectobius lapponicus* (Linnaeus, 1758)	Ela					2		1		3	
	Diplura	Campodeidae	*Campodea fragilis* (Meinert, 1865)	Cfr	1		1	2					2	2
	Hemiptera	Pyrrhocoridae	*Pyrrhocoris apterus* (Linnaeus, 1758)	Pap	50		2		5		2	1	59	1
		Pentatomidae	*Zicrona caerulea* (Linnaeus, 1758)	Zca	27								27	
		Lygaeidae	*Lygaeus equestris* (Linnaeus, 1758)	Leq					5		1		6	
Myriapoda	Diplopoda	Julidae	*Schyzophyllum sabulosum* (Linnaeus, 1758)	Ssa	2		1	1	1				4	1
	Chilopoda	Geophilidae	*Cryptos hortensis* (Donovan, 1810)	Cho	2			1					2	1
	Scutigeromorpha	Scutigeridae	*Scutigera coleoptrata* (Linnaeus, 1758)	Sco			1						1	
	Polydesmida	Polydesmidae	*Polydesmus angustus* (Latzel, 1884)	Pan	1		3						4	
Crustacea	Isopoda	Oniscidae	*Oniscus asellus* (Linnaeus, 1758)	Oac	11	2	2						13	2
Oligocheta	Opistophora	Lumbricidae	*Lumbricus terrestris* (Linnaeus, 1758)	Lte	1		1	2	5	5	49	1	56	8
Total individuals					152	15	30	13	71	11	66	22	319	61
Total species					19	12	21	11	18	6	17	11	34	27

Table 2
Abundance, species richness, diversity and evenness of soil invertebrates as a function of the soil tillage management, experimental site and year. M, Mahassen; K, Krib, H', Shannon–Weaver diversity index; D, Margalef diversity index. Different letters in columns for each parameter indicate that there was a significant difference ($P > 0.05$) between NT and CT.

Site/year	Species richness		Density		Evenness		H' diversity		D diversity	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
M_02-03	19[a]	12[b]	152[a]	15[b]	0.66	0.91	2.71	2.73	3.19	2.59
M_03-04	21[a]	11[b]	30[a]	13[b]	0.96	0.97	4.02	3.09	4.99	3.12
K_02-03	18[a]	6[b]	71[a]	11[b]	0.88	0.86	3.54	2.22	3.52	3.26
K_03-04	17[a]	11[b]	66[a]	22[b]	0.46[a]	0.92[b]	1.74[a]	3.17[b]	3.10	2.09
Mean	18.75	10	79.75	15.25	0.74	0.92	3.00	2.80	3.70	2.77

Soil invertebrates were captured for each tillage system (CT or NT) at seven times in 2 sites (Mahassen and Krib) and at 2 cereal growing seasons (2002–2003 and 2003–2004) using the quadrat method.

total abundance. Among Insecta, Coleoptera was the most dominant order, with a ratio of 18/31, and 35.3% of total abundance. Four species of Myriapoda were recorded, with a 3.4% of total abundance. Crustacea with 1 species (*Oniscus asellus*) made 3.9% of total abundance. Earthworms (*Lumbricus terrestris*) represent 16.8% of the total abundance. A total of 210 individuals (26 species) were collected in Mahassen vs. 170 individuals (23 species) in Krib (Table 1). The most abundant families (>10 individuals in both tillage systems) were *geotrupidae*, *scarabaeidae*, *mélolenthidae*, *chrysomelidae*, *carabidae*, *blattidae*, *pyrrhocoridae*, *pentatomidae*, *oniscidae* and *lumbricidae*. All these families showed significantly higher proportions under NT than CT considering the total individuals captured in both sites during the 2 growing seasons.

Over the experiment duration (2002–2004), total number of soil invertebrates under CT (61 ind.) was significantly ($P < 0.05$) lower than that under NT (319 ind.). Significantly ($P < 0.01$) more species were also captured in NT (34 species) than in CT (26 species).

In most of the cases, the diversity (D and H') of the soil invertebrates was either higher or equal in NT than in CT, except for in Krib site in 2003–2004 where H' and E were lower under NT than under CT due to the dominance of earthworms. The evenness index in Mahassen was also lower during 2002–2003 where the invertebrate communities were dominated by *Blattidae*, *Pyrrhocoridae* and *Pentatomidae* (Table 2).

The multifactor ANOVA (site, year, and tillage system) showed that only the tillage system had significant effect in reducing the number of species captured in the 2 sites under the 2 CT systems (Table 3). Among all groups, the mean density of individuals in the soil varied significantly according to soil management system. The multivariate analysis showed that the species distribution in the CA plan [1; 2] indicates that the 2 other factors (year and site) are also effective. When the 2 sites, the two years, tillage systems and all species collected were taken into account, the CA showed a direct association between invertebrate species, years and sites.

Table 3
Results of the multifactor ANOVA.

Factors	Summ square	DF	Average square	F-test	P-value
Site	5.11	1	5.11	0.18	0.67
Year	74.27	1	74.27	2.65	0.10
Tillage type	252.15	1	252.15	8.99	0.00
Site vs. Year	46.89	1	46.89	1.67	0.20
Site vs. Tillage system	10.75	1	10.75	0.38	0.54
Year vs. Tillage system	49.18	1	49.18	1.75	0.19
Site vs. Year vs. Tillage system	57.04	1	57.04	2.03	0.15

Soil invertebrates were captured for each tillage system (CT or NT) at seven times in 2 sites (Mahassen and Krib) and at 2 cereal growing seasons (2002–2003 and 2003–2004) using the quadrat method.

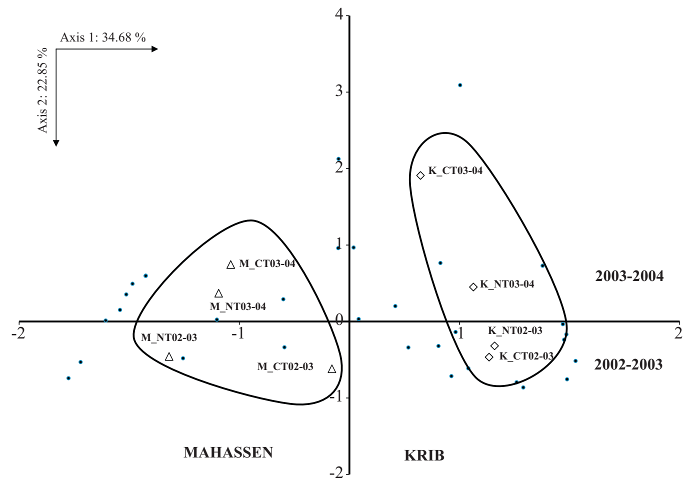

Fig. 3. Correspondence analysis plotted for both sites (Mahassen △ and Krib ◇), years (2002–2003 and 2003–2004) and all invertebrate species (•) and for both tillage systems (CT and NT). Data used were log ($x + 1$) transformed. Soil invertebrates were captured for each tillage system (CT or NT) at four times; 2 sites (Mahassen and Krib) × 2 cereal growing seasons (2002–2003 and 2003–2004) using the quadrat method.

Morover, axis-1 (34.7%) opposes most 2002–2003 variables to those of 2003–2004, while axis-2 (22.9%) opposes variables from Mahassen to those from Krib. The same figure shows that there was a site and year effects on invertebrate populations (Fig. 3).

Within most groups, the invertebrate population density, in the soil, varied significantly according to the soil management system. When comparing the relative proportion of dominant groups (Coleoptera, Myriapoda, Crustacea,Oligocheta, and others), the Chi-square test showed significant differences (Mahassen $P < 0.001$; Krib $P = 0.048$) between NT and CT. Indeed, invertebrates were most abundant in quadrats from NT plots than from CT plots. When groups were taken separately, only Coleoptera, Oligocheta and other insects had significantly ($P < 0.05$) lower proportions in CT than in NT (Fig. 4).

When the index of change was calculated at the level of major groups or taxonomic entities, results showed that all values were negative, and all groups had greater abundance in NT than in CT (Fig. 5).

3.2. Pitfall trap sampling method

A total of 313 invertebrates (235 at Mahassen vs. 78 at Krib) belonging to 24 species, 18 families, 8 orders, 4 classes and 2 phyla were captured in all traps in the 2 sites and for both tillage systems. Captured number of invertebrates in 2004 with pitfall traps was significantly ($P < 0.01$) less under CT than under NT at both sites (Table 4).

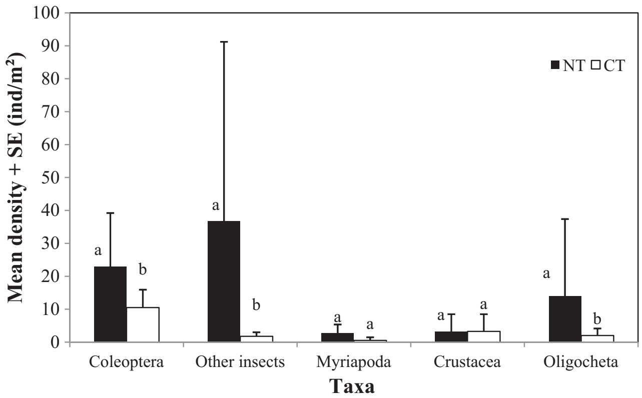

Fig. 4. Distribution (mean density + SE) of soil invertebrates (major groups) as a function of the soil management system. Soil invertebrates were captured for each tillage system (CT or NT) at four times; 2 sites (Mahassen and Krib) × 2 cereal growing seasons (2002–2003 and 2003–2004) using the quadrat method. For each group, bars followed by different letters are significantly different (*t*-student test). SE: standard error.

The Insecta class was the most abundant, accounting for 93.25% and 89% of the total individuals in Mahassen and Krib, respectively, and followed by Oligocheta (<5%).

The species richness was of the same order for both sites (20 species vs. 18 species for, Mahassen and Krib, respectively). Fourteen (14) species were common for both sites. Four (4) species over 18 exist at Krib and 6 species over 20 were captured at Mahassen and not at Krib. Different proportions of taxa were observed as a function of tillage system. Nevertheless, the most abundant families (>10 individuals in both tillage systems) were *scarabaeidae*, *aphodiidae*, *carabidae*, *elatridae*, *silphidae*, *formicidae* and *lumbricidae*. In Mahassen, all previous families showed significantly ($P < 0.05$) lower proportions in CT than in NT. However, differences were not significant in Krib. Coleoptera was the most abundant order making 78.1% and 58.3% of the total invertebrates at Mahassen and Krib, respectively. At Mahassen the proportion of this order was significantly ($Chi^2 = 59.6$; $P < 0.001$) higher under NT than under CT. The proportions of the other orders, pooled together, were significantly lower in CT than in NT ($Chi^2 = 19.7$; $P < 0.001$).

Fig. 6A and B shows the seasonal dynamics of invertebrates as Coleoptera or other groups. Throughout the season, the number of Coleoptera and other groups at Mahassen was significantly higher in NT than in CT. No significant differences were observed at Krib. In both sites, the aggregated number of invertebrates shows a highly significant difference between NT and CT (Fig. 6 A and B). Mean H' diversity was higher under NT than under CT in Mahassen, but the evenness was of equal value. At Krib, similar values were observed under the two tillage systems.

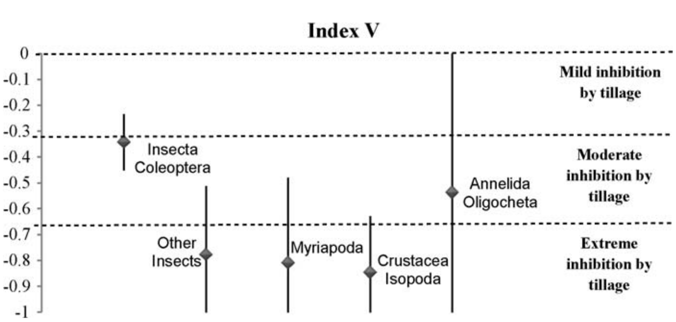

Fig. 5. Variance of the mean of the index V (as described in the text) for the major taxonomic group. Species were captured by quadrat method during two growing season (2002–2003 and 2003–2004) at two sites (Mahassen and Krib).

4. Discussion

No-till (NT) systems have less mechanical mixing of crop residues with soil minerals than the conventional till (CT) systems. So, NT systems are likely undisturbed ecosystems and may depend more on soil organisms for proper functioning (House and Parmelee, 1985; Kladivko, 2001). Our results showed that NT enhanced the soil fauna populations either in diversity or in abundance in the two sites, which confirm our first hypothesis. The negative effect of CT on richness and diversity of soil fauna community in relation to NT systems was suggested in the literature (House and Parmelee, 1985; Stinner et al., 1988; Kladivko, 2001; Marasas et al., 2001; Blanchart et al., 2006; Rodrıguez et al., 2006). The negative impact of CT on ecosystem engineers and functional guilds (arthropods and earthworms) was also clear in our study. As we hypothesized, the move from CT to NT improved soil biological component which could be explained by two factors: the change of soil properties as demonstrated by Ben Moussa-Machraoui et al. (2010) and reduce of the number of machine passes over the field, so lack of disturbance.

When residues are left on soil surface the ecosystem engineers (worms and other organisms) and litter transformers may become much more important than in disturbed (residues incorporated) ecosystems. Recently, Ben Moussa-Machraoui et al. (2010) showed that under semi-arid conditions in north-west of Tunisia (Mahassen, Krib), NT improves soil properties and crop yield when compared to CT. NT, significantly, improved soil content especially for K, K_2O, P_2O5 and N. Cover residues as crops combined with NT appear to improve some agronomic parameters of production (tiller/plant; grain/ear; harvest index, 1000 kernel weight) and grain yield. Indeed, over 4-year experiment, the same authors indicated that clay and silt soils can be affected over a short time by tillage management. Soil organic matter showed higher values under NT, but results were not significant from those of CT. However, under NT agroecosytems earthworms and micro-arthropods played a dominant role in organic matter decay, therefore, nutrient flux patterns (House and Parmelee, 1985). Moreover, the soil fauna of natural ecosystems influences organic matter decay and mineralization process, making a better availability of nutrients for crop growth (Petersen and Luxton, 1982).

Abundance, biodiversity and population densities of soil invertebrates, especially arthropod and earthworm communities, were significantly higher under NT system than under CT, 3 years after the implementation of these systems. These findings are consistent with those of several authors in providing evidence of a positive contribution of NT to biodiversity, abundance and population densities of soil fauna (House and Parmelee, 1985; Stinner et al., 1988; Blanchart et al., 2006; Rodrıguez et al., 2006). Since 1999 no soil disturbance contributes in this area to the higher densities of soil fauna under NT (Ben Moussa-Machraoui et al., 2010). Moreover, crop residues improve environmental conditions for soil organisms by protecting habitats against water, wind, temperature and soil humidity and by increasing organic matter as feed resources. So, a more stable environment was provided for soil invertebrates (Kladivko, 2001). In the long term, NT promotes organic matter, nutrient and microbial activity near the soil surface (Doran, 1980). Therefore, soil faunal interactions are more pronounced and the organic matter decay and nutrient release are controlled by a mix of soil fauna (House and Parmelee, 1985). In this particular study, the combination of several data method analyses (ANOVA and CA) was applied to demonstrate a real effect of tillage management on the density of soil fauna population. This was the case, as NT reduces the disturbance imposed on soil faunal communities known under CT (Fereres, 1997). The slight difference between sites and among the two years could be due to the

Table 4
Abundance of invertebrates captured as a function of soil management system (CT vs. NT) and the two experimental sites (Mahassen and Krib). Soil fauna was sampled by 4 pitfall traps per plot. Species were captured during the 2004 durum wheat growing season. Each value corresponds to the pooled data from four traps. CT, conventional tillage; NT, no-tillage; *H′*, Shannon index; *E*, evenness.

Taxa	Order	Family	Species	Mahassen														Krib													
				NT							CT							NT							CT						
				J	F	M	A	M	J	J	J	F	M	A	M	J	J	J	F	M	A	M	J	J	J	F	M	A	M	J	J
Ins	Coleoptera	Geotrupidae	*Geotrupes stercorarius* (Linnaeus, 1758)			10	4	7	4				2		2	4					3	4						2		1	1
		Scarabaeidae	*Onthophagus ovatus* (Linnaeus, 1767)			14	10		5	1			1			4												2	1		1
			Diplotaxis tristis (Kirby, 1837)		1				2										1	1	1										
		Melolonthidae	*Amphimallon solstitialis* (Linnaeus, 1758)																	1							1				
		Aphodiidae	*Calamosternus granarius* (Linnaeus, 1767)						12							2						2	1	2		1	1				
		Carabidae	*Tomoxia bucephala* (Costa, 1854)			12	6	2	2	17					1		3			4											
			Agonum placidum (Say, 1823)					3							3															1	1
			Carabus monilis (Fabricius, 1792)			1	1		1	1						5															
		Elatridae	*Agriotes spitator* (Linnaeus, 1758)			6		9		3			1	1	1		3														
		Curcilionidae	*Calandra granaria* (Linnaeus, 1758)													3															
		Staphilinidae	*Ocypus olens* (Müller, 1764)												2																
			Dromius agilis (Fabricius, 1787)																			1									
		Coccinellidae	*Coccinella septempunctata* (Linnaeus, 1758)																								1				
		Bruchidae	*Bruchus pisorum* (Linnaeus, 1758)			3																									1
		Silphidae	*Silpha carinata* (Herbst, 1783)				5	3								2			2	1								1	2		
	Dermaptera	Forficulidae	*Forficula auricularia* (Linnaeus, 1758)	1		2	2						1										1	6							1
	Hymenoptera	Formicidae	*Lasius fuliginosus* (Latreille, 1798)		2			5	3	10																					
		Dolicoderidae	*Formica rufa* (Linnaeus, 1761)						1								3						2						1	1	
			Iridomyrmex humilis (Mayr, 1868)													2							3								
	Hemiptera	Pyrrhocoridae	*Pyrrhocoris apterus* (Linnaeus, 1758)	1							2	1						5								2					
Myr	Julida	Julidae	*Schyzophyllum sabulosum* (Linnaeus, 1758)		1													1								1	1				
	Scutigeromorpha	Scutigeridae	*Scutigera coleoptrata* (Linnaeus, 1758)																2		2					1	1				
Crus	Isopoda	Oniscidae	*Oniscus asellus* (Linnaeus, 1758)	2				1		2								2											1		
Ann	Opistophora	Lumbricidae	*Lumbricus terrestris* (Linnaeus, 1758)	1	8						1																				
Total individuals				5	12	48	28	30	30	34	3	1	5	1	9	22	9	8	5	7	6	7	7	8	0	4	4	5	5	3	5
Total species				4	4	7	6	7	8	6	2	1	4	1	5	7	3	3	2	4	2	3	4	2	0	3	4	3	4	3	5
H′				1.9	1.4	2.4	2.3	2.5	2.5	1.9	0.9	0	1.9	0	2.2	2.7	1.6	1.3	1.5	1.7	1.5	1.4	1.8	0.8	0	1.5	2.0	1.5	1.9	1.6	2.3
E				0.9	0.7	0.9	0.9	0.9	0.9	0.7	0.9	-	0.9	-	0.9	0.9	1	0.8	0.9	0.8	0.9	0.9	0.9	0.8	-	0.9	1	0.9	0.4	1	1

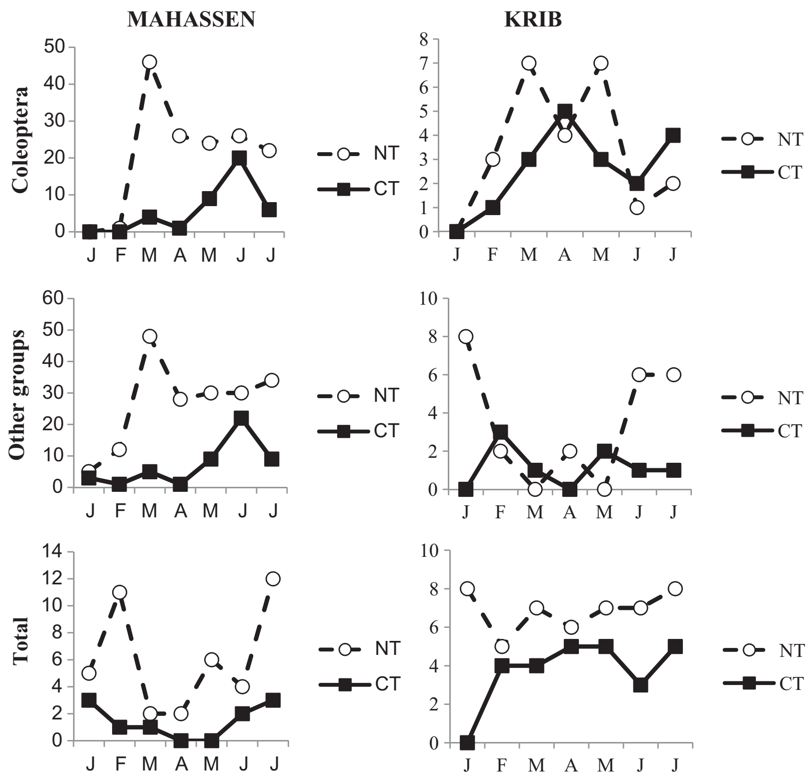

Fig. 6. Seasonal dynamics of total invertebrates, Coleoptera and other groups separately, from conventional and no-tillage systems. Invertebrates were captured using 4 pitfall traps per plot and tillage system.

local ecological factors, especially the rainfall which can reduce the arthropod activity. However, more precipitations were recorded in 2003–2004 growing season than in 2002–2003 and in Krib than in Mahessen.

Overall, CT showed substantial influence on density and diversity of several taxonomic groups (Table 2). Such result was confirmed by the biological *V* index (all values are negative and less than −0.33; Fig. 5).

Effects of CT on invertebrate populations could be partially attributed to the physical disturbance by CT. Some individuals may be killed initially by abrasion during tillage or by being trapped under soil layers after tillage.

4.1. Effects of tillage on soil arthropods

Results show that the move from CT to NT enhances the soil arthropod richness, abundance and diversity, which improve the soil biological component, confirming our hypothesis. Results showed that Arthropod phylum was the most abundant group in both sites (Mahassen, Krib) over two years (2002/2003 and 2003/2004). Brévault et al. (2007) also showed that Arthropod animals were the most abundant, accounting for >92.7% of the total individuals, with Insecta >78.5% of total Arthropods. Insecta was the most abundant class, where essentially Coleoptera was the main population component. Across the season, they increased in NT plots than in CT ones (Table 1, Fig. 6). The most dominant family of this order was Carabidae, representing 29% and 39% of total Coleoptera collected with the quadrat and pitfall trap methods, respectively. Carabidae community, as the most abundant family of predators, was significantly higher under NT than under CT for both sampling methods. The difference in Carabidae community composition and diversity between the two tillage systems supports the findings that agronomic practices can have significant impacts on generalist predator communities (Stinner et al., 1988; Stinner and House, 1990; Brévault et al., 2007; Menalled et al., 2007). Results confirmed that predators (Carabidae) were in greater abundance in NT plots than in CT ones. CT can reduce carabidae abundance and diversity due to mortality and disruption of over wintering sites and through a decrease in the availability of suitable prey and alternative feed resources (Purvis and Fadl, 2002). Thus, these results can highlight the close relationship between agronomic management practices and generalist predator activity. As they act at the top of the feed chain and feed on other organisms, Carabidae made a major and ecologically important group of generalist arthropod predators in this study. These arthropods are known to be predators of several insect, pests, plants, weed seeds and fungi (Stinner and House, 1990). Their populations increased under NT systems and the presence of other groups with higher population densities associated to the crop residues may enhance their populations.

The detritivore group, mainly represented by Formicidae and Dolicoderidae, were more abundant in NT than in CT, either for pitfall trap or for quadrat method (where 64.3% and 80.9% of these families being collected in NT plots). Similar results were found in other semi-arid regions (Rodrıguez et al., 2006). Contrasting results were however obtained by Stinner et al. (1988), where authors showed that tillage did not influence detritivore numbers significantly. Detritivore group is particularly important because they act as catalysts in the process of organic matter decay (Lavelle et al., 1997). Accumulation of organic matter in NT as a product of crop residues (Ben Moussa-Machraoui et al., 2010) may provide a resource base for these detritivores (Blanchart et al., 2006). In semi-arid zones, ants (Formicidae) influence soil properties more than earthworms (Lal, 1988). In this study, such results are supported by the fact that the number of anthill counted was numerically higher in NT than in CT. Anthill can also improve soil macroporosity, which in turn improves the availability of water to plants (Lobry de Bruyn, 1999).

Herbivore group, mainly represented in this study by Julidae, Pyrrhocoridae and some Scarabaeidae, is more abundant in NT plots than in CT plots. Similar results were reported by Stinner and House (1990), stating that mulch provides a favourable habitat and feed resource for several soil arthropods, usually herbivores. Coprophagous group is represented in this study by Scarabaeidae, Geotupidae and Aphodiidae. Most of these species are known by their role in the disappearance of herbivore dung. Scarabaeidae and Geotrupidae are diggers, whereas Aphodiidae are dwellers (Lumaret and Kirk, 1987). In addition, the larval stage of many dung beetles living in the soil and residue surface is important for maintaining appropriate water content of soil and temperature (Cochran et al., 1994). CT reduces the population of these beneficial arthropods (Lumaret and Kirk, 1987; Robertson et al., 1994). Tillage disrupts the habitat and removes the essential reproduction sites and nests or resources for these beetles.

4.2. Tillage effect on earthworms

Earthworms form a large part of the macrofauna in many soils, affecting soil properties through their feeding, casting and burrowing activities (Kladivko, 2001). Numerous research examples support the fact that the reduction of tillage intensity enhances earthworm populations (House and Parmelee, 1985; Brown, 1995; Kladivko, 2001; Chan, 2001; Capowiez et al., 2009; Peigné et al., 2009). Chan (2001) indicated that total earthworm populations under NT can be 2–9 times greater than those found under CT. Boone et al. (1976) reported that after 5 years of NT on a fine texture (clay) soil, the earthworm population was 3 times that of ploughed treatment (90–270 worms/m^2). Similar results were obtained by other authors (House and Parmelee, 1985; Brown, 1995; Kladivko, 2001; Capowiez et al., 2009; Peigné et al., 2009). In this study, earthworm populations were almost higher or equal under NT than under CT. *L. terrestris* is the only species that pulled the crop residues down several centimeters from the opening of its burrow, where it feeds on it after some initial microbial decomposition. Tillage is known to affect their populations through feed supply (Kladivko, 2001) and chemical environment (Ben Moussa-Machraoui et al., 2010). In NT plots, crop residues on the soil surface are available for this species for a longer period of time when compared with CT, where residues are incorporated in the soil. *L.* terrestris is considered as a deep-burrowing species (Bouché, 1977). They feed primarily on residues, pulling them into their permanent burrow. Surface feed supply is not present in tilled soils, and the top portion of the permanent burrow must be reformed after any tillage (Kladivko, 2001). Consequently, a few specimens are present in tilled plots in the present findings.

So, Arthropod and earthworms constitute a beneficial component of NT, since they have a catalytic role in surface crop residue decay. This pattern is thought to be due to an accumulation of organic matter on or near the surface of NT soil (as reported by Ben Moussa-Machraoui et al., 2010). Tillage accelerates decomposition of organic matter by stimulating microbial activity and lowering the diversity of the soil fauna community (House and Parmelee, 1985). These confirm our second hypothesis. In addition, tillage accelerates crop residue decay by generating homogenous soil-litter conditions, whereas under NT, nutrients are immobilized within surface crop residues, making a slow release of nutrients for a longer period which promotes the density and the diversity of soil invertebrates.

5. Conclusion

According to the results of this study, soil fauna is influenced by the tillage management under Mediterranean semi-arid conditions. NT practices favoured more soil arthropod fauna (abundance and in diversity) and for some cases more earthworm density than did CT. Compared to CT, NT favoured the establishment of predators (Carabidae), detritivores (earthworms, ants) and herbivores (some Coleoptera and Myriapods).

So, the move from CT to NT stimulates soil faunal populations and could be beneficial to agricultural ecosystems. Therefore, it may encourage greater biological complexity and can mimic the structure of natural agroecosystems.

Further investigations are necessary to relate density and diversity of soil invertebrates to beneficial agriculture products. Furthermore, it would be of greater interest to replicate the experiment with other crop species such as barley, oat or pea. Finally, a long term experiment will confirm better that the relationship of diversity of soil invertebrates was or not related to management systems. i.e., greater invertebrate abundance and diversity to tillage management, whether NT or CT.

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References

Baker, C.J., Saxton, K.E., Ritchie, W.R., 2002. No-tillage Seeding: Science and Practice, 2nd edition. CAB International, Oxford, UK.
Ben Hammouda, M., Guesmi, M., Nasr, K., Khammassi, M., 2004. Evolution de la matière organique en semis direct et conventionnel. In: Deuxièmes rencontres méditerranéennes sur le semis direct. Tabarka, Tunisie pp. 104–107.
Ben Salem, H., Zaibet, L., Ben Hammouda, M., 2006. Perspectives de l'adoption du semis direct en Tunisie. Une approche économique. Cah. Opt. Médit. 69, 69–75.
Ben Moussa-Machraoui, S., Errouissi, F., Ben-Hammouda, M., Nouira, S., 2010. Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in northwestern Tunisia. Soil Till. Res. 106, 247–253.
Blanchart, E., Villenave, C., Viallatoux, A., Barthe's, B., Girardin, C., Azontonde, A., Fellera, C., 2006. Long-term effect of a legume cover crop (Mucuna pruriens var. utilis) on the communities of soil macrofauna and nematofauna, under maize cultivation, in southern Benin. Appl. Soil Ecol. 42, 136–144.
Bouché, M.B., 1977. Stratégies lombriciennes. In: Lohm, U., Persson, T. (Eds.), Soil Organisms as Components of Ecosystems, vol. 25. Biol. Bull., (Stockholm), pp. 122–132.
Boone, F.R., Slager, S., Miedema, R., Eleveld, R., 1976. Some influences of zerotillage on the structure and stability of a fine-textured levee soil. Neth. J. Agric. Sci. 24, 105–119.
Brévault, T., Bikay, S., Maldes, J.M., Naudin, K., 2007. Impact of a no-till with mulch soil management strategy on soil macrofauna communities in a cotton cropping system. Soil Till. Res. 97, 140–149.
Brown, G.G., 1995. How do earthworms affect microbial and faunal community diversity? Plant Soil 170, 209–231.
Capowiez, Y., Cadoux, S., Bouchant, P., Ruy, S., Roger-Estrade, J., Richard, G., Boizard, H., 2009. The effect of tillage type and cropping system on earthworm communities, macroporosity and water infiltration. Soil Till. Res. 105, 209–216.
Chan, K.Y., 2001. An overview of some tillage impacts on earthworm population abundance and diversity-implications for functioning in soils. Soil Till. Res. 57, 179–191.
Chivenge, P.P., Murwira, H.K., Giller, K.E., Mapfumo, P., Six, J., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: implication for conservation agriculture on contrasting soils. Soil Till. Res. 94, 328–337.
Cochran, V.L., Sparrow, S.D., Sparrow, E.B., 1994. Residues effects on soil micro- and macroorganisms. In: Unger, P.W. (Ed.), Managing Agricultural Residues. CRC Press, Boca Raton, FL, pp. 163–184.
Daget, J., 1976. Les modèles mathématiques en écologie. Masson, Paris, France.
Doran, J.W., 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44, 765–771.
Edwards, C.A. (Ed.), 1998. Earthworm Ecology. St. Lucie Press, Boca Raton, FL, p. 389.
Edwards, C.A., Bohlen, P., 1995. Biology and Ecology of Earthworms. Chapman and Hall, New York.
Fereres, A., 1997. Control de insectos-plaga en laboreo de conservación. In: García Torres, L., González Fernández, P. (Eds.), Agricultura de conservación: Fundamentos Agronómicos. Medioambientales y Económicos, pp. 143–155.
Francis, G.S., Fraser, P.M., 1998. The effects of three earthworm species on soil macroporosity and hydraulic conductivity. Appl. Soil Ecol. 10, 11–19.

Franzluebbers, A.J., 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Till. Res. 66, 197–205.
Giesy, J.P., Dobson, S., Solomon, K.R., 2000. Ecotoxicological risk assessment for Roundup herbicide. Rev. Environ. Contam. Toxicol. 167, 35–120.
Girard, M.C., Walter, C., Rémy, J.C., Berthelin, J., Morel, L. (Eds.), 2005. Sols et environnement. Dunod Sciences sup Cours, exercices et études de cas (2e cycle/ master, écoles d'ingénieurs, professionnels), 816 pp.
Hendrix, P.F. (Ed.), 1995. Earthworm Ecology and Biogeography in North America. Lewis Publishers, Boca Raton, FL, p. 244.
House, G.J., Parmelee, R.W., 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Till. Res. 5, 351–360.
Ito, M., Matsumoto, T., Quinones, M.A., 2006. Conservation tillage practice in sub-Saharan Africa: the experience of Sasakawa Global 2000. Crop Prot. 26, 417–423.
Kladivko, E.J., 2001. Tillage systems and soil ecology. Soil Till. Res. 61, 61–76.
Lal, R., 1988. Effects of macrofauna on soil properties in tropical ecosystems. Agric. Ecosyst. Environ. 24, 101–116.
Lal, R., Reicosky, D.L., Hanson, J.D., 2007. Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil Till. Res. 93, 1–12.
Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Rober, P., Incson, P., Heal, O.W., Dhillion, S., 1997. Soil function in a changing world: the role of invertebrate ecosystem engineers. Eur. J. Soil Biol. 33, 159–193.
Lee, K.E., 1985. Earthworms, Their Ecology and Relationships with Soils and Land Use. Academic Press, Sydney.
Lobry de Bruyn, C.A., 1999. Ants as bioindicators of soil function in rural environments. Agric. Ecosyst. Environ. 74, 425–441.
Lumaret, J.P., Kirk, A.A., 1987. Ecology of dung beetles in the French Mediterranean region (Coleoptera: Scarabaeidae). Acta Zool. Mex. 24, 1–55.
Marasas, M.E., Sarandon, S.J., Cicchino, A.C., 2001. Changes in soil arthropod functional group in a wheat crop under conventional and no tillage systems in Argentina. Appl. Soil Ecol. 18, 61–68.
Menalled, F., Smith, R.G., Dauer, J.T., Fox, T.B., 2007. Impact of agricultural management on carabid communities and weed seed predation. Agric. Ecosyst. Environ. 118, 49–54.
Ouedraogo, E., Mando, A., Brussaard, L., 2006. Soil macrofauna affect crop nitrogen and water use efficiencies in semi-arid West Africa. Eur. J. Soil Biol. 42, 275–277.
Peigné, J., Cannavaciuolo, M., Gautronneau, Y., Aveline, A., Giteau, J.L., Cluzeau, D., 2009. Earthworm populations under different tillage systems in organic farming. Soil Till. Res. 104, 207–214.
Petersen, H., Luxton, M., 1982. A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos 39, 287–388.
Pfiffner, L., Luka, H., 2007. Earthworm population in two low-input cereal farming systems. Appl. Soil Ecol. 37, 184–191.
Purvis, G., Fadl, A., 2002. The influence of cropping rotations and soil cultivation practice on the population ecology of carabids (Coleoptera: Carabidae) in arable land. Pedobiologia 46, 452–474.
Richard, J.F., 2007. L'expérience de l'agriculture de conservation dans le monde. In: Séminaire National de lancement du projet d'appui au développement de l'agriculture de conservation. Bizerte, Tunisie, pp. 16–17.
Robertson, L.N., Kettle, B.A., Simpson, G.B., 1994. The influence of tillage practices on soil macrofauna in a semi-arid agroecosystem in northeastern Australia. Agric. Ecosyst. Environ. 48, 149–156.
Rodrıguez, E., Fernandez-Anero, F.J., Ruiz, P., Campos, M., 2006. Soil arthropod abundance under conventional and no tillage in a Mediterranean climate. Soil Till. Res. 85, 229–233.
Stinner, B.R., Mc Catney, D.A., Van Doren, D.M., 1988. Soil and foliage arthropod communities in conventional, reduced and no-tillage corn systems: a comparison after 20 years of continuous cropping. Soil Till. Res. 11, 147–158.
Stinner, B.R., House, G.J., 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Annu. Rev. Entomol. 35, 299–318.
Thomas, G.A., Dalal, R.C., Standley, J., 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil Till. Res. 94, 295–304.
Wardle, D.A., 1995. Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. Adv. Ecol. Res. 26, 105–185.
Winter, J.P., Voroney, R.P., Ainsworth, D.A., 1990. Soil microarthropods in long-term no-tillage and conventional tillage corn production. Can. J. Soil Sci. 70, 641–653.