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SPATIO-TEMPORAL VARIATION OF TERRESTRIAL ISOPOD DIVERSITY IN THE BIZERTE AGROECOSYSTEMS (NORTH-EAST OF TUNISIA)

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TERRESTRIAL ISOPOD
DIVERSITY
AGROECOSYSTEMS
TUNISIA

ABSTRACT. – In Tunisia, the diversity of epigeic arthropods was studied for the first time in a cultivated area. In this study, we focused on terrestrial Isopods (Oniscidea) in Bizerte agroecosystems (NE of Tunisia). Isopods were sampled at 8 plots in the sectors of Ghar El Melh and Utique, using pitfall traps. In the field, five pitfall traps were randomly placed in each plot during 4 seasons from autumn (October 2009) to summer (July 2010). In the laboratory, isopods were identified and counted. Overall, seven species of terrestrial isopods were recorded. *Porcellio laevis* Latreille, 1804 was present whatever the season, plot and sector. *Armadillidium album* Dollfus, 1887 and *Armadillidium tunisiense* Hamaïed & Charfi-Cheikhrouha, 2007 were found only in the sector of Ghar El Melh. Differences in the composition and abundance of terrestrial isopods could be attributed to soil characteristics recorded in all plots.

INTRODUCTION

The relationship between agriculture and biodiversity has been analyzed in several publications (e.g., Altieri 1999, Pfiffner & Luka 2000). According to Pfiffner & Luka (2000), there is a general trend in agricultural landscape towards a reduction in diversity and abundance of native flora and fauna because of increased landscape uniformity and greater disturbance due for example to agrochemicals and tillage. The intensification of agricultural production has led to a significant decrease of Carabid beetles diversity (Hawthornea *et al*. 1998). Altieri (1999) showed that enhancing functional biodiversity in agroecosystems is a key ecological strategy to bring sustainability to production. Thus, the development of agroecological technologies and systems, which emphasizes the conservation-regeneration of biodiversity of fauna, soil, water, and other resources, is urgently needed to reach socioeconomic and environmental challenges (Altieri 1999).

The soil biota plays an essential role in soil function as it is involved in processes such as organic matter decomposition, humus formation and nutrient cycling of many elements (nitrogen, carbon, etc.) (Power 2010). Among the soil fauna, arthropods play a major role in agriculture as they are essential components of the biodiversity of cultivated ecosystems (Fuller *et al*. 1995). Among these organisms, terrestrial isopods play a major role because of their important function in decomposing leaf litter and mineralizing organic matter in ecosystems (Zimmer *et al*. 2003), and particularly in agricultural lands. Their impact as possible pests in agroecosystems is limited. Faberi *et al*. (2011) showed that *Armadillidium vulgare* (Latreille, 1804) was an important pest in some crops in Argentina. In Tunisia, isopods are observed in inlands (forests, maquis), meadows and near wet places, for example near the beach, oueds and irrigated agroecosystems (Hamaïed-Melki *et al*. 2010, Fraj-Lagha 2013, Khemaissia *et al*. 2016). Fraj *et al*. (2010) proved that isopods are relevant bioindicators for sustaining soil health and quality in Majerda agroecosystems in North-East of Tunisia. The type of agroecosystems also affected terrestrial isopods diversity (Souty-Grosset *et al*. 2005a). On one hand, it has been observed that isopods tend to be more abundant in semi natural grasslands than in woodlands and more abundant in woodlands than in cultivated land (Davis & Sutton 1978, Souty-Grosset *et al*. 2005a, b, 2008). On the other hand, a notable difference in species composition was observed between deciduous woodlands and cultivated areas. For example, in Italy, *Trachelipus razzautii* (Arcangeli, 1913), commonly present near hedgerows, is absent from crop fields (Paoletti 1988, Paoletti & Hassall 1999).

The present study is a part of an ongoing research attempting to estimate the diversity of arthropods related to agricultural practices in the agroecosystems of Majerda valley, the most important basin in Tunisia. Preliminary results from Fraj *et al*. (2010) showed that the diversity of terrestrial isopods varied in autumn according to the type of cultivation and the mode of irrigation. The sprinkler was considered as a favorable irrigation practice to maintain isopod diversity. Isopods were more diverse in vegetable crops than in orchards and market gardening cultivation (Fraj-Lagha *et al*. 2014).

The aim of this paper is to compare the seasonal distribution of isopods in two sectors of the Bizerte agroecosystems in the North-East of Tunisia. Additionally, the effects of soil characteristics on the isopod communities and species distribution will be discussed.

MATERIALS AND METHODS

The study area (250,000 ha) was situated in the Majerda valley (North-East of Tunisia) located between Bizerte and Tunis city (Fig. 1). This site has a Mediterranean climate and belongs to the upper semi-arid region. The daily mean air temperature varied between 11° C (January: winter) and 27° C (August: summer) and the relative air humidity oscillated between 65 and 80 %. The annual average precipitation was around 433 mm. The landscape was dominated by agricultural land use. In the Majerda agroecosystems, irrigation was an important agricultural activity and the surface system of irrigation was the most commonly used (Abbes *et al*. 2005). In this area, two sectors (Ghar El Melh and Utique) were selected for isopod sampling. The agronomical characteristics of each sector such as cultivation types (Table I), irrigation systems and quality of water used for irrigation were revealed from the field work. In each sector, 4 plots were sampled (GEM1, GEM2, GEM3 and GEM4 in the Ghar El Melh sector and UTQ1, UTQ2, UTQ3 and UTQ4 in the Utique sector). Seven plots were irrigated by the water from the lower valley. One plot (GEM1) was irrigated by the water of tidal phenomenon (High tide).

Terrestrial isopods were sampled during October 2009, January, April and July 2010 (three consecutive weeks each month), using pitfall traps (plastic cups, 7 cm height, 5.5 cm diameter, 1/4 filled with 70 % ethylene glycol), a suitable method to observe epigeic activity of soil-dwelling animals. This sampling method gave a good approximation of epigeic isopod abundance (Topping & Sunderland 1992, Matalin & Makarov 2011). At each plot, 5 traps were placed and 3 sampling replicates were realized (traps were emptied every 7 days). A total of 15 traps per plot and season were used. Individual traps were put up in a linear transect and 5 foot steps distant from each other. Pitfall traps were dug into the soil so that the rim of each cup was at the soil surface level. To prevent flooding and overflow from rain, we covered each trap with a plastic plate, mounted above the trap to leave a 3 cm-high entrance on all sides. Isopods were preserved in 70 % ethanol, counted and identified at the species level using a Leica MS 5 binocular microscope and the key species identification of Vandel (1962), Medini-Bouaziz (2002) and Hamaïed-Melki (2008).

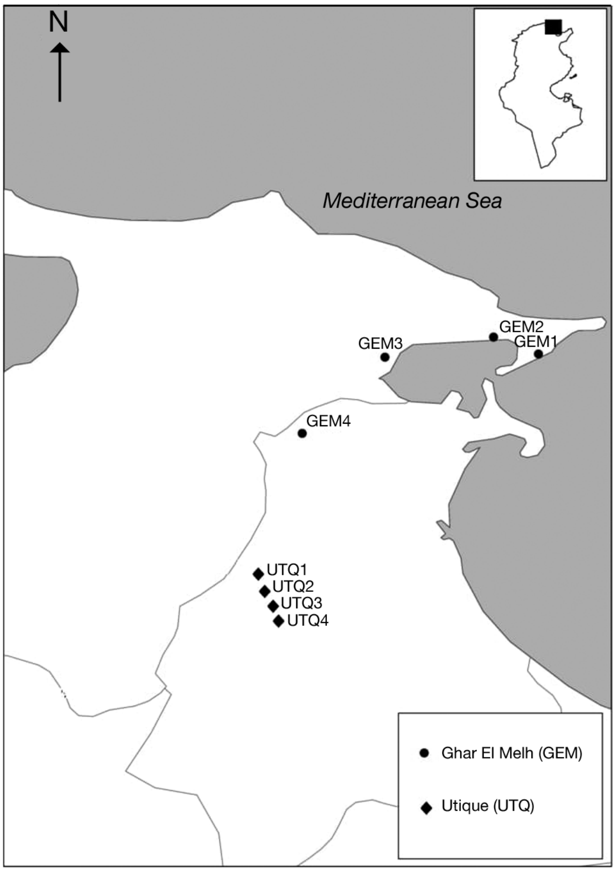

Fig. 1. – Localization of sampling plots.

Soil samples were taken at 3 depths (surface, 5 and 10 cm) 3 times during isopod trapping, in each season and each plot. In the laboratory, soil fauna, plant parts or stones were discarded from the soil samples by hand. In each season and at the end of

Table I. – Characteristics of studied plots. EC: End of cultivation.

Sector	Abbr	GPS Coordinates	Cultivation autumn	Cultivation winter	Cultivation spring	Cultivation summer	Area (ha)
Ghar El Melh	GEM1	37°06’42.2”N/010°04’55.2”E	No cultivation	Potato	Potato	Potato (EC)	3
Ghar El Melh	GEM2	37°09’42.3”N/010°08’10.9”E	No cultivation	Potato	Potato	Maize (FC)	0.5
Ghar El Melh	GEM3	37°10’14.3”N/010°12’ 28.6”E	Tomato	Potato	Potato	Potato (EC)	3
Ghar El Melh	GEM4	37°09’33.4”N/010°14’36.8”E	Tomato	Potato	Potato	Potato (EC)	3
Utique	UTQ1	37°01’04.8”N/010°03’08.2”E	Maize	Corn	Corn	Corn (EC)	3
Utique	UTQ2	37°01’04.9”N/010°03’08.7”E	Sorghum	Corn	Corn	Corn (EC)	3
Utique	UTQ3	37°00’44.7”N/010°03’17.7”E	Melon	Corn	Corn	Corn (EC)	3
Utique	UTQ4	37°00’24.1”N/010°03’27.8”E	Squash	Chickpeas	Chickpeas	Chickpeas (EC)	1

the isopod sampling, the 3 soil samples were pooled and regarded as one composite sample for physicochemical soil analysis. Soil pH and conductivity were measured in a soil-water suspension. An EUTEH Instruments (pH 510) pH meter was used to measure the pH water and pH KCl. Conductivity was measured on the suspension, which was left overnight in order to allow the bulk of the soil to settle, using a WTW Multi 340i/ SET conductivity meter.

Seasonal activity-density (AD ± SD) of the isopod assemblages were estimated as the average number of individuals captured per trap in each plot. Diversity was estimated from the Shannon-Wiener index (H') as following: $H' = -\sum_{i=1}^{S}[Pi \times \log_2 Pi]$ (Pi = relative frequency = [ni (number of individuals of species i)/N (total number of individuals)] and S: species richness). The evenness index $J' = H' / \log_2 S$ was calculated to assess the evenness of isopod species assemblages. A Principal Component Analysis (PCA) was performed to relate isopod species abundance and soil descriptors.

All data were analyzed for normality by the Shapiro test. Differences in isopod activity-density among plots and sectors were compared by ANOVA. The above statistical calculations were performed using R (Husson *et al*. 2009) and Primer 5 (Clarke & Gorley 2003) software.

RESULTS

Total species richness, activity-density and occurrence frequency

A total of 463 isopods belonging to 7 species and to 2 families, Porcellionidae and Armadillidiidae, were captured (Table II). Total species richness (S total) (Fig. 2) varied between 2 (autumn) and 7 (winter), whereas Activity-Density (AD total) was inversely proportional to S. The maximum value of AD (13.57) was observed in autumn and the minimum in winter (6.85). Moreover, the occurrence frequency of species fluctuated between seasons (Fig. 2), and *Porcellio laevis* was the most frequent species (45 % in autumn, 61 % in winter, 52 % in spring and 72 % in summer). *Porcellio variabilis* was the second most frequent species and most often encountered in sampled plots (55 % in autumn, 13 % in winter, 26 % in spring and 7 % in summer). The other species (*Armadillidium album*, *A. tunisiense*, *Porcellionides sexfasciatus*, *Leptothricus panzeri* and *Agabiformius lentus*) exhibited low frequency in all seasons.

Spatio-temporal variation of Oniscidea community

In each season, the maximum of species richness was observed in GEM2 plot (S = 2 in autumn, 5 in winter, 3 in spring and 4 in summer) (Table II). Two *Armadillidium* species were exclusive for Ghar El Melh sector, *A. album* in the GEM1 (close to the sea) and *A. tunisiense* in the GEM2 (near to the lagoon) and GEM4 (inland plots). Those aforementioned species were rare in the studied area. Others were ubiquitous such as *P. laevis* and *P. variabilis,* which were found in all plots. According to the season, each plot exhibited a particular species composition (Table II). In autumn, only *P. laevis* and *P. variabilis* were present in both studied sectors. *Porcellio variabilis* was the most dominant species (6.6 ± 3.59) in UTQ2 plot (sorghum cultivation). In winter, 6 species were recorded in Ghar El Melh and 3 species in Utique sector. *Armadillidium* species and *A. lentus* were found in potato cultivation (GEM1 and GEM2 plots). These

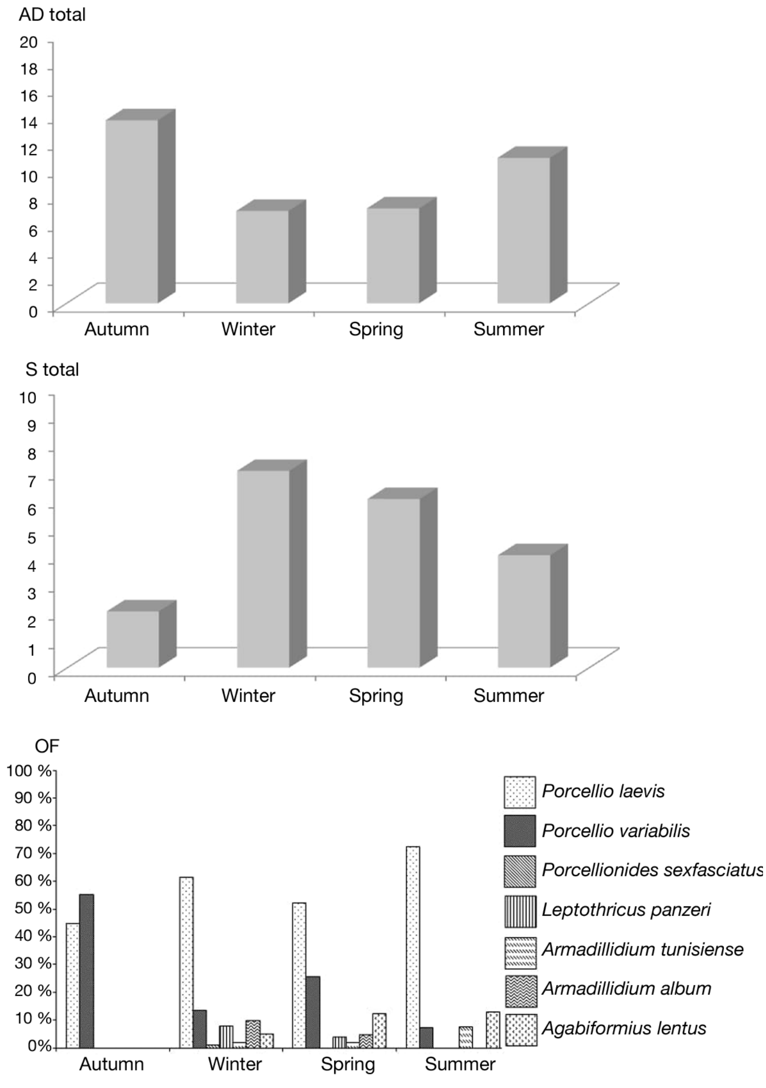

Fig. 2. – Seasonal variation of total activity-density (AD), total Species richness (S) and occurrence frequency (OF).

Table II. – Isopods activity-density in the different plots in each season (mean followed by SD).

	GEM1	GEM2	GEM3	GEM4	UTQ1	UTQ2	UTQ3	UTQ4
Autumn								
Porcellio laevis (Latreille, 1804)	0	0.06 (0.06)	1.28 (0.41)	0.53 (0.13)	1.6 (0.36)	1.13 (0.42)	0.8 (0.29)	0.66 (0.28)
Porcellio variabilis (Lucas, 1846)	0	0.13 (0.13)	0.57 (0.38)	0	0.2 (0.14)	6.6 (3.59)	0	0
Porcellionides sexfasciatus (Budde-Lund, 1879)	0	0	0	0	0	0	0	0
Leptothricus panzeri (Audouin, 1826)	0	0	0	0	0	0	0	0
Armadillidium tunisiense (Hamaïed & Charfi-Cheikhrouha, 2007)	0	0	0	0	0	0	0	0
Armadillidium album (Dollfus, 1887)	0	0	0	0	0	0	0	0
Agabiformius lentus (Budde-Lund, 1885)	0	0	0	0	0	0	0	0
Total	0	0.2 (0.14)	1.85 (0.74)	0.53 (0.13)	1.8 (0.38)	7.73 (3.59)	0.8 (0.29)	0.66 (0.28)
Winter								
Porcellio laevis (Latreille, 1804)	0.06 (0.06)	0.33 (0.21)	2.85 (0.82)	0.46 (0.27)	0.46 (0.32)	0	0	0
Porcellio variabilis (Lucas, 1846)	0.06 (0.07)	0.06 (0.07)	0	0	0.13 (0.13)	0.46 (0.22)	0,00	0.2 (0.14)
Porcellionides sexfasciatus (Budde-Lund, 1879)	0	0	0	0	0	0	0	0.06 (0.07)
Leptothricus panzeri (Audouin, 1826)	0	0.13 (0.09)	0.14 (0.14)	0.26 (0.15)	0	0	0	0
Armadillidium tunisiense (Hamaïed & Charfi-Cheikhrouha, 2007)	0	0.13 (0.09)	0	0	0	0	0	0
Armadillidium album (Dollfus, 1887)	0.66 (0.43)	0	0	0	0	0	0	0
Agabiformius lentus (Budde-Lund, 1885)	0.2 (0.20)	0.13 (0.09)	0	0	0	0	0	0
Total	1 (0.45)	0.8 (0.34)	3 (0.80)	0.73 (0.37)	0.6 (0.41)	0.46 (0.22)	0	0.26 (0.15)
Spring								
Porcellio laevis (Latreille, 1804)	0	0.4 (0.21)	1.86 (0.52)	0.53 (0.17)	0.4 (0.16)	0.06 (0.07)	0.26 (0.12)	0.13 (0.13)
Porcellio variabilis (Lucas, 1846)	0	0.06 (0.06)	0	0	0.13 (0.09)	1.6 (0.51)	0	0
Porcellionides sexfasciatus (Budde-Lund, 1879)	0	0	0	0	0	0	0	0
Leptothricus panzeri (Audouin, 1826)	0	0	0.26 (0.15)	0	0	0	0	0
Armadillidium tunisiense (Hamaïed & Charfi-Cheikhrouha, 2007)	0	0.06 (0.06)	0	0.06 (0.06)	0	0	0	0
Armadillidium album (Dollfus, 1887)	0.33 (0.15)	0	0	0	0	0	0	0
Agabiformius lentus (Budde-Lund, 1885)	0.86 (0.33)	0	0	0	0	0	0	0
Total	1.2 (0.46)	0.53 (0.27)	2.13 (0.57)	0.6 (0.19)	0.53 (0.19)	1.66 (0.54)	0.26 (0.12)	0.13 (0.13)
Summer								
Porcellio laevis (Latreille, 1804)	0	5.86 (0.19)	0.66 (0.36)	0.2 (0.10)	0.4 (0.16)	0.6 (0.23)	0.07 (0.07)	0
Porcellio variabilis (Lucas, 1846)	0	0.06 (0.06)	0	0	0.33 (0.27)	0.4 (0.23)	0	0
Porcellionides sexfasciatus (Budde-Lund, 1879)	0	0	0	0	0	0	0	0
Leptothricus panzeri (Audouin, 1826)	0	0	0	0	0	0	0	0
Armadillidium tunisiense (Hamaïed & Charfi-Cheikhrouha, 2007)	0	0.8 (0.40)	0	0	0	0	0	0
Armadillidium album (Dollfus, 1887)	0	0	0	0	0	0	0	0
Agabiformius lentus (Budde-Lund, 1885)	0.93 (0.52)	0.33 (0.33)	0	0	0	0.13 (0.13)	0	0
Total	0.93 (0.52)	7.06 (1.73)	0.66 (0.36)	0.2 (0.10)	0.73 (0.40)	1.13 (0.27)	0.07 (0.07)	0

Table III. – One way ANOVA in each season related to plot and sector. ns: no significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$.

	Autumn		Winter		Spring		Summer	
	Plots	Sectors	Plots	Sectors	Plots	Sectors	Plots	Sectors
Porcellio laevis (Latreille, 1804)	***	**	***	**	***	**	***	*
Porcellio variabilis (Lucas, 1846)	**	ns	*	*	ns	*	ns	ns
Porcellionides sexfasciatus (Budde-Lund, 1879)	ns	ns	ns	ns	ns	ns	ns	ns
Leptothricus panzeri (Audouin, 1826)	ns	ns	ns	*	**	ns	ns	ns
Armadillidium tunisiense (Hamaïed & Charfi-Cheikhrouha, 2007)	ns	ns	*	ns	ns	ns	***	ns
Armadillidium album (Dollfus, 1887)	ns	ns	*	ns	***	ns	ns	ns
Agabiformius lentus (Budde-Lund, 1885)	ns	ns	ns	ns	***	*	*	ns

Table IV. – Shannon (H ± SE) and Evenness (J ± SE) diversity indices related to the plot and the season.

	Autumn		Winter		Spring		Summer	
	H	J	H	J	H	J	H	J
GEM1	0	0	0	0	0.16 ± 0.28	0.27 ± 0.43	0	0
GEM2	0	0	0.10 ± 0.29	0.18 ± 0.40	0.04 ± 0.14	0.07 ± 0.24	0.05 ± 0.14	0.58 ± 0.19
GEM3	0.092 ± 0.24	0.22 ± 0.44	0	0	0.07 ± 0.20	0.23 ± 0.40	0	0
GEM4	0	0	0.07 ± 0.2	0.12 ± 0.30	0.05 ± 0.17	0.11 ± 0.33	0	0
UTQ1	0.046 ± 0.17	0.25 ± 0.5	0.04 ± 0.17	0.07 ± 0.25	0.05 ± 0.17	0.1 ± 0.31	0.08 ± 0.23	0.16 ± 0.37
UTQ2	0.17 ± 0.25	0.38 ± 0.40	0	0	0.03 ± 0.13	0.08 ± 0.24	0	0
UTQ3	0	0	0	0	0	0	0	0
UTQ4	0	0	0	0	0	0	0	0

Table V. – Soil physicochemical descriptors of different collection plots.

	Grain size	Soil humidity (%)	pH water	pH KCl	Conductivity (µS/cm)	Na+ (mg/g)	Ca2+ (mg/g)
GEM1	Sandy	4.4 ± 2.4	7.31 ± 0.32	7.15 ± 0.31	145 ± 62.41	0.01 ± 0.01	0.20 ± 0.11
GEM2	Sandy-loam	12.6 ± 3.9	7.85 ± 0.43	7.59 ± 0.28	217.5 ± 134.76	0.28 ± 0.48	0.92 ± 0.95
GEM3	Sandy-loam	14.7 ± 1.4	7.59 ± 0.21	7.32 ± 0.08	362.75 ± 187.61	0.03 ± 0.02	0.44 ± 0.31
GEM4	Sandy-loam	15.2 ± 1.6	7.70 ± 0.23	7.32 ± 0.24	236.75 ± 97.87	0.07 ± 0.03	0.32 ± 0.22
UTQ1	Sandy	12.8 ± 4.9	8.19 ± 0.40	7.48 ± 0.18	284.75 ± 34.94	0.09 ± 0.07	0.46 ± 0.09
UTQ2	Sandy	13.7 ± 3.2	8.20 ± 0.24	7.60 ± 0.14	589.75 ± 272.65	0.07 ± 0.05	0.58 ± 0.58
UTQ3	Sandy	14.0 ± 6.2	8.01 ± 0.45	7.35 ± 0.23	265.75 ± 91.91	0.04 ± 0.02	0.41 ± 0.10
UTQ4	Sandy	11.1 ± 5.6	8.03 ± 0.12	7.57 ± 0.10	245.25 ± 109.23	0.08 ± 0.04	0.49 ± 0.20

plots were situated in the littoral zone of the Ghar El Melh region and characterized by high soil moisture. *Porcellio sexfasciatus* was present in Utique sector with low abundance (0.06 ± 0.07). In spring, 6 species were found in Ghar El Melh and 2 in Utique sector. Only *P. sexfasciatus* was absent in the first sector. In the second sector, only the two ubiquitous species (*P. laevis* and *P. variabilis*) were present. In summer, two *Porcellio*, one *Armadillidium*, one *Agabiformius* species were recorded in Ghar El Melh sector. Three species were found (*P. laevis*, *P. variabilis* and *A. lentus*) in Utique. The *Agabiformius* species (0.13 ± 0.13) was found for the first time in Utique (UTQ2: end of the corn cultivation). The one way ANOVA showed significant differences between plots and sectors for some species within a season (Table III).

Shannon diversity and Pielou's evenness indices show season and plot variations (Table IV). The highest Shannon diversity value was recorded in UTQ2 (sorghum: H = 0.17 ± 0.25) in autumn, in GEM2 (potato: H = 0.10 ± 0.29) in winter, in GEM1 (potato: H = 0.16 ± 0.28) in spring and in UTQ1 (corn: H = 0.08 ± 0.23) in summer. The same pattern was found for the evenness index (UTQ2: J = 0.38 ± 0.40, GEM2: J = 0.18 ± 0.40, GEM1: J = 0.28 ± 0.43 and GEM2: J = 0.58 ± 0.19). We can also deduce that the value of Shannon found in the different plots and seasons was very low (from 0 to 0.17 ± 0.25) and the isopod communities were not distributed equally (except for GEM2 during summer).

The physicochemical descriptors of different collected plots are summarized in Table V. The studied plots differed

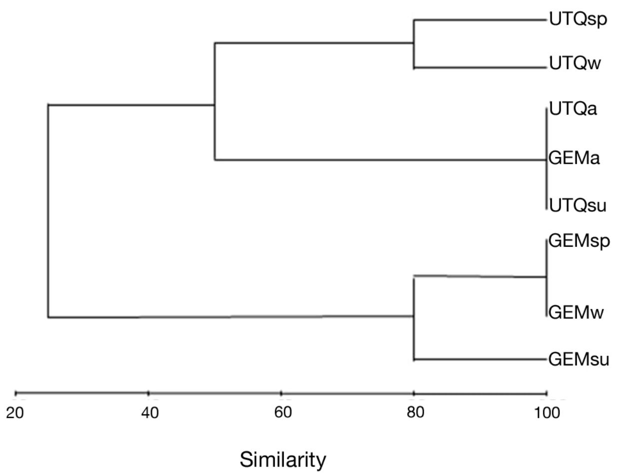

Fig 3. – Clustering of sampling data, based on total number of isopods collected in all plots and seasons (Bray-Curtis index, presence/absence, complete linkage). a: autumn, w: winter, su: summer and sp: spring.

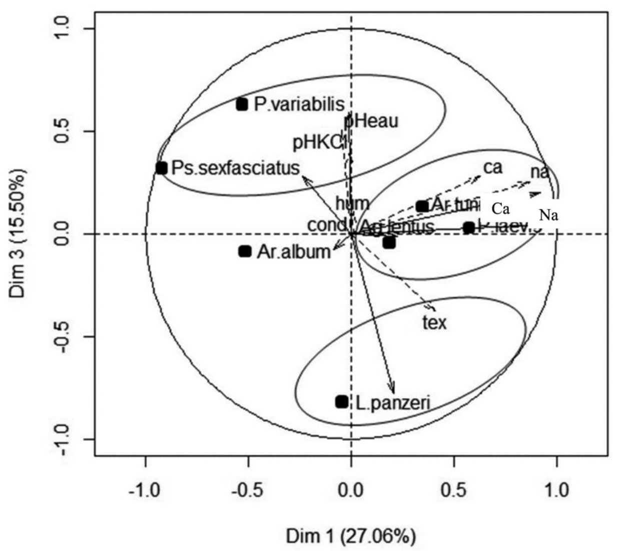

Fig. 4. – Principal Component Analysis (PCA) on isopods species and soils descriptors. P. laevis: *Porcellio laevis*, P. variabilis: *Porcellio variabilis*, Ag. lentus: *Agabiformius lentus*, L. panzeri: *Leptotrichus panzeri*, Ar. album: *Armadillidium album*, Ar. tunisiense: *Armadillidium tunisiense*, Ps. sexfasciatus: *Porcellionides sexfasciatus*. Ca: content of calcium, cond: conductivity of soil, Hum: Humidity of soil, Na = content of sodium, tex: texture of soil.

in substratum composition, ranging from sandy (GEM1, UTQ1, UTQ2, UTQ3 and UTQ4) to sandy-loam (GEM2, GEM3 and GEM4). The lowest value of different chemicals soil descriptors were found in GEM1 plot (Table V). The maximum of soil humidity was observed in GEM4 plot. The plot UTQ2 present the highest value of soil pH water, pH KCl and conductivity. A maximum content of Na^+ and Ca^{2+} was measured in the GEM2 (0.28 ± 0.48 and 0.92 ± 0.95, respectively). We found a significant effect of plot only on the mean value of soil humidity ($F = 2.97$; $p < 0.025$) and conductivity ($F = 3.56$; $p < 0.001$).

The community similarity based on the Bray-Curtis index showed that the studied sectors in all seasons were clustered according to presence/absence of species (Fig. 3). In fact, the dendrogram recovered two main groups, the first representing only the plots of GEM sectors in spring, winter and summer while the second cluster group the plots of UTQ sector and the GEM plots studied in autumn. This second cluster could be divided into two subclusters with a similarity close to 50 %. The aforementioned results shown that the isopod communities studied are individually restricted per sector, and a clear separation per season was found. In each sector, the isopod assemblages studied in winter and spring were very similar with the other seasons (summer and autumn).

A Principal Component Analysis was performed to better understand which environmental factors influenced the seasonal distribution of species (Fig. 4). PCA showed that species occurrence correlated with plot characteristics: 27.06 % of the information was obtained through the first axis and an additional 15.50 % by the third axis. In fact, *P. laevis* was abundant in all seasons, *A. lentus* and *A. tunisiense* were present only in winter, spring and summer and were clearly associated with Na^+ and Ca^{2+}. *Porcellio variabilis* and *P. sexfasciatus* were correlated with the soil pH (water and KCl). Also, *L. panzeri* was positively related to the soil grain size.

DISCUSSION

We studied the diversity and composition of assemblages of terrestrial isopods in a Bizerte agroecosystems.

A relatively moderate number of species (7 species) was recorded in the two cultivated sectors belonging to the Majerda agroecosystems. Achouri *et al.* (2008a) collected 12 species of terrestrial isopods from natural and uncultivated habitats in the Berkoukech catchment area (Kroumirie), in the North-West of Tunisia. The investigation of Hamaïed-Melki *et al.* (2010) recorded 11 species in the northwestern Wadi Moula-Bouterfess catchment area (Kroumirie). Nevertheless, differences in species richness between cultivated and natural regions can be explained by the fact that isopods are particularly sensitive to a lower quality of their habitat due to anthropogenic influence (irrigation systems, rotation of crops, and types of soil cultivation) in agroecosystems (Paoletti & Hassal 1999). Moreover, concerning the global analysis of species abundance, *P. laevis* and *P. variabilis* were the most abundant species as they were found in all studied plots and in each season. These species were already considered as widespread in Tunisia (from the North to the South) by Medini-Bouaziz (2002) and Medini-Bouaziz *et al.* (2015), colonizing different types of habitats. In the natural ecosystem in northern Tunisia, *P. variabilis* was the most abundant species and *P. laevis* was absent (Achouri *et al.* 2008a, Hamaïed-Melki *et al.* 2010). In the

Oued Laou region in North-East of Morocco, Achouri *et al*. (2008b) reported that *P. laevis* was abundant in all natural habitats with diverse vegetation and elevation. The *Armadillidium* species were present only in the plots of Ghar El Melh situated near to the sea and the lagoon (littoral) characterized by high soil moisture. All other species (*P. sexfasciatus*, *L. panzeri, A. lentus*) were poorly represented, whatever the sampling plot and type of cultivation. In general, in this present study, isopod species were markedly depleted in the plots of Utique characterized by the relatively dry condition of the soil and in cereal cultivation, compared with Ghar El Melh plots in gardening cultivation. It has been documented that isopods prefer habitats with high humidity (Vandel 1962, Hornung 2011). The seasonal variation of frequency occurrence and abundance of Oniscidean species was observed in the two studied sites of Ghar El Melh and Utique, thus confirming the result of Fraj-Lagha *et al*. (2014) in some agroecosystems. Like in Kalaat El Andalouss, Sidi Thabet and Sidi Othman, *P. laevis* and *P. variabilis* were, also, the most frequent and abundant species in all seasons. Indeed, our work showed that the *A. lentus* species was the most frequent species in spring and summer (12 % and 13 %, respectively). This result was likely due to the ecological preference of these two species that were generally found in arid environment (Vandel 1962). The supralittoral species *A. album* was present only in winter (10 %) and spring (5 %). A possible explanation could be related to the higher humidity of soil during these two seasons, which had an effect on isopod distribution. Also, the occurrence and the activity-density of other species (such as *Armadillo officinalis*), classified sporadic or accidental, varied between seasons (Messina *et al*. 2012). It has been demonstrated that the dominant woodlice species changed according to the time of the year (Souty-Grosset *et al*. 2005b).

The distribution of terrestrial isopods was investigated related to the plot characteristics using PCA. Our statistical analyses indicated that the variation in the distribution of isopods depended on factors like temperature, humidity and the type of habitat, which is influenced by soil quality. The multivariate analysis also indicated that the distribution of *P. laevis*, *A. lentus* and *A. tunisiense* was driven by the ion (Na^+ and Ca^{2+}) content because isopods are generally in need of Ca^{2+} due their exoskeleton (Zimmer *et al*. 2002). However, Khemaissia *et al*. (2012) showed that in the supralittoral habitat in Ghar El Melh site, the Ca^{2+} content has no influence on isopod distribution. Soil pH was shown to control the distribution of *P. variabilis* and *P. sexfasciatus* in agroecosystems area. Woodlice have been shown to react to variations in pH. Some species such as *Armadillidium vulgare,* present in many forests in Poitou-Charentes (France), were more sensitive to acid pH than *Porcellio muscorum* (Souty-Grosset *et al*. 2005a). Finally, only *L. panzeri* depended to the grain size of soil. All others species were indifferent to the soil type. In Netherlands agroecosystems, some isopod species, such as *Ligidium hypnorum,* preferred the clay and peat soil, while *Philoscia muscorum*, the most dominant species, has no preferences for a specific soil type (Berg & Hemerik 2004).

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