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Effects of soil management practices on the abundance, biomass and diversity of soil macrofauna in the province of Berkane, NE Morocco

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Abstract

The agrobiodiversity in the province of Berkane along the Triffa plain of the NE region of Morocco represents an area characterized by a high diversity of ecosystems that are affected by intense agricultural activities. Therefore, it is essential to study the different agricultural practices that contribute to its protection and preservation. However, no biological measurements are currently being carried out in this region. Between February and April 2023, a set of 30 soil sampling sites was established in six sugar beet fields from two agricultural systems to evaluate the effects of soil management practices on soil macrofaunal communities, litter and soil properties in a Beta vulgaris L. (sugar beet) field in Berkane. In this study, the transition from conventional to organic cultivation has a positive effect on the macrofauna communities, which also contributed to changes in soil edaphic properties. For example, the abundance of macrofauna, was greater in the organic system (780 ± 190 individuals · m^{-2}) than in the conventional farming system (296 ± 69 individuals · m^{-2}). Additionally, the biomass of soil macrofauna increased almost twofold during the transition to the organic farming system. However, the diversity was similar between the two different agricultural systems, with a slight increase in specific richness in the organic farming system compared with that in the other conventional farming system. We assume that the feedback of soil macrofauna to farming systems could be due to the indirect impact of pesticides via changes in habitat conditions.

1. Introduction

Until recently, the oriental region of the Moroccan kingdom has been one of the least known Moroccan regions in terms of its biological soil composition. Currently, measurements for soil monitoring in the province of Berkane, which is known for its intense agricultural activity, are exclusively physical (bulk density, temperature, pH, cation exchange capacity (CEC) etc.) or chemical (trace element content, organic matter (OM), etc.), and no biological measurements are currently being carried out in this region. The diversity of soil fauna in this region is still largely unknown and deserves to be studied. The diversification and richness of its natural environment, as well as its geographical position, offer the province of Berkane potential and a favorable climate for agricultural activities.

Soil fauna communities are essential part of agricultural ecosystems, and play important roles in ecosystem functioning and the provision of ecosystem services (Lavelle, 1996; van Eekeren et al., 2008; Wolters and Ekschmitt, 1997). They contribute to the decomposition of plant litter, affect the structure and function of the microorganism community of soil (Ristok et al., 2019), and alter the structure and edaphic properties of soil (Lavelle et al., 1994; Niemeyer et al., 2012; Rousseau et al., 2013; Ugarte et al., 2013). The essential contributions of soil organisms can be threatened by soil management practices, including agricultural intensification by overuse of land, nutrient imbalance, inadequate land use management practices (Foley et al., 2005; Fragoso et al., 1997; Giller et al., 1997), and the use of phytosanitary products (Fox, 1964; Pelosi et al., 2014). Additionally, the use of pesticides in crops could have a significant effect on nontarget soil

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fauna (Hassan et al., 1994). These factors contribute to changes in the habitat environment, which can have synergistic effects and therefore pose a particular threat to soil organisms and ecosystem functions. The sugar beet crop is considered one of the main sources of sugar production worldwide, ranking as the second source with a percentage covering approximately 30% of the world's global sucrose production (Dohm et al., 2014). In Morocco, the area harvested for sugar beet production is 38.794 ha, with production of 1.898039 million tons during 2022 (FAO, 2024). In the province of Berkane, this crop represents an important economy. In fact, for better production, phytosanitary products (insecticides, herbicides) are widely used against weeds, pests of Beta vulgaris L. (sugar beet) cultivation. Their intensive use can have a significant negative impact on soil fauna, and consequently could affect the edaphic properties of soil. However, most studies in this region, focus on measurements of human impacts on the physicochemical properties of soil, and no biological measurements have been performed.

In this framework, the present research aimed to contribute to fill the current knowledge about the impacts of diverse agricultural soil management on abundance, diversity and biomass of soil macrofauna communities in Moroccan ecosystems. Based on previous studies (Coulis, 2021; Suárez et al., 2019), it can be hypothesized that, (1) organic soils have higher diversity and abundance of soil macrofauna than the conventional soils, and (2) these differences will be affected by the soil physicochemical properties and the use of herbicides.

Therefore, this study focuses on the first characterization of soil biodiversity in Berkane region, NE Morocco. Our aims were to: (1) contribute to the knowledge of the soil fauna community under sugar beet crops, and (2) study the impact of agricultural systems as well as the transition toward sustainable cropping systems on these soil organisms. This study will provide novel insights into the ecological value of anthropized soils and highlights how soil management practices shape soil biodiversity and ecosystem function.

2. Materials and methods

2.1. Study area

The study area is located in the extreme northeast region of the Kingdom of Morocco, in the Oriental region, of the province of Berkane (35°00'00.85''N, 2°14'18.63''O). This area consists of a mosaic of agricultural fields (sugar beets, pastures and clementine plots) and urban areas (Fig. 1). The agricultural sector is considered one of the pillars of the province's economy, covering

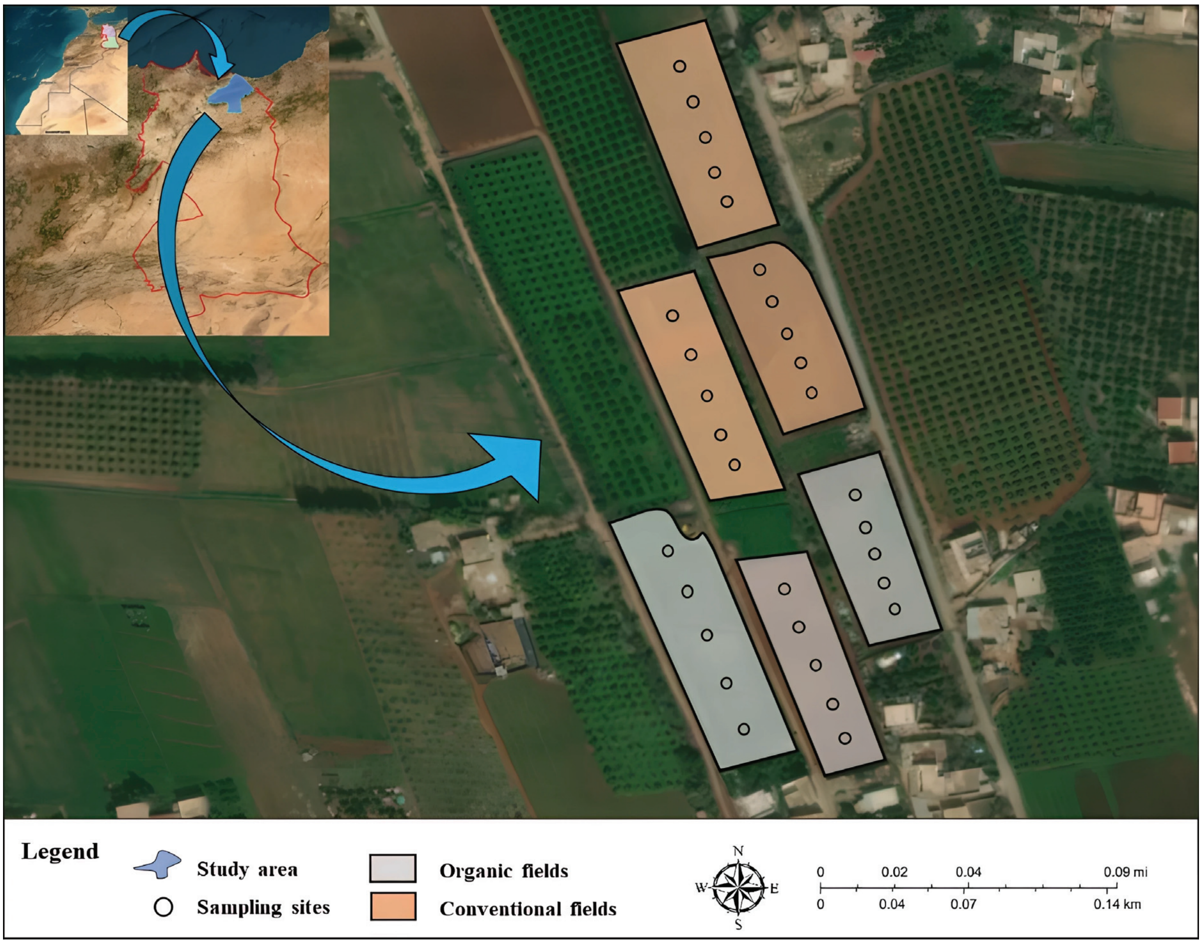

Fig. 1. Geographical location of six sugar beet fields from two agricultural systems

a cultivable area of 92576 ha (46% of the total area of the province). The study area is characterized by a semi-arid Mediterranean climate, a hot and dry summer. Winter is rainy and cold. Precipitation decreases along a north-south gradient. The average annual rainfall is low and irregular (371 mm). Rainfall, which is small throughout the year, is generally concentrated in the period from December to April. Average annual temperatures range from 12 to 15 degrees in winter and 24 to 25.6 degrees in summer (Fig. 2). For the past three years, farmers have been actively engaged and have taken actions to transition to sustainable agriculture. This study was carried out in six sugar beet fields from two agricultural systems, covering a total of 2.47 ha. (1.12 ha for organic fields and 1.35 ha for conventional fields), all of which are located in proximity. This distance was retained to avoid the introduction of other factors while remaining under similar climatic and topsoil conditions (Fig. 1). Conversion to organic farming has been undergoing conversion for three years, and no fertilizers, fungicides, herbicides or insecticides are used at these sites. To avoid weed emergence and intermediate crops, two types of sustainable weeding practices were carried out, manual weeding and mechanical weeding through passages with harrows (depending on their growth). Soil fertility is based on the use of FERTINOVA® organic fertilizers, products found in the Moroccan market, which are FERTINOVA GALINATOP products, composed of hygienized and granulated poultry manure. FERTINOVA K^+ 2N-2P-8P, from balanced mixtures of animal and plant origin, contains all the components necessary for the plant cycle and FERTINOVA PLUS 2N-3P-2K, from the recovery by composting agricultural waste, agroindustry and livestock. These fertilizers are spread at a rate of approximately 150 $kg.ha^{-1}$. For the other conventional fields, fertilization is carried out via enriched fertilizers (14N-23P-14K) applied at a rate of 100 $kg.ha^{-1}$. For weed control, herbicides (based on the active ingredients of glyphosate, propaquizafop, foramsulfuron, fluazifop-P-butyl, metamitrone, clethodim, cycloxydim and S-metolachlor) were used during the three years preceding sampling. These farming practices in the region allow farmers to achieve high agricultural productivity.

2.2. Sampling and identification of soil macrofauna

A set of 30 soil macroinvertebrate sampling sites were studied in the six sugar beet fields during the period between February 06 and April 09, 2023. In each field, five sites were established along a transect, making a total of 30 independent sampling sites, to represent the different soil faunal communities. For each sample, soil macrofauna sampling was carried out via two complementary collection methods: the Tropical Soil Biology and Fertility method (TSBF) (Anderson and Ingram, 1994), and pitfall traps placed around each TSBF sampling point. The first method consists of manual sorting of a block of soil from a pit on surfaces delimited by a metal frame of 25 cm x 25 cm sides at a depth of 15 cm. In short, the litter is removed and sorted manually on site, followed by manual sorting of the first 15 cm of soil. The collected macroinvertebrates were preserved in a pillbox with formaldehyde concentrated at 4% until identification in the laboratory. The second method uses 3 plastic containers filled with a liquid mixture of three elements (table salt, detergent, and water) (Souza et al., 2012), which are sunk into the ground to trap and intercept macroinvertebrates circulating on the soil surface except earthworms, and collected every 7 days. The data collected from these harvests enabled us to determine the relative abundance of macrofauna circulating on the ground of the soil. The soil macroinvertebrates collected by these two methods (Barber pitfall trap and TSBF) are counted, and then identified to the order, family and species levels if possible, in collaboration with specialists and available documents.

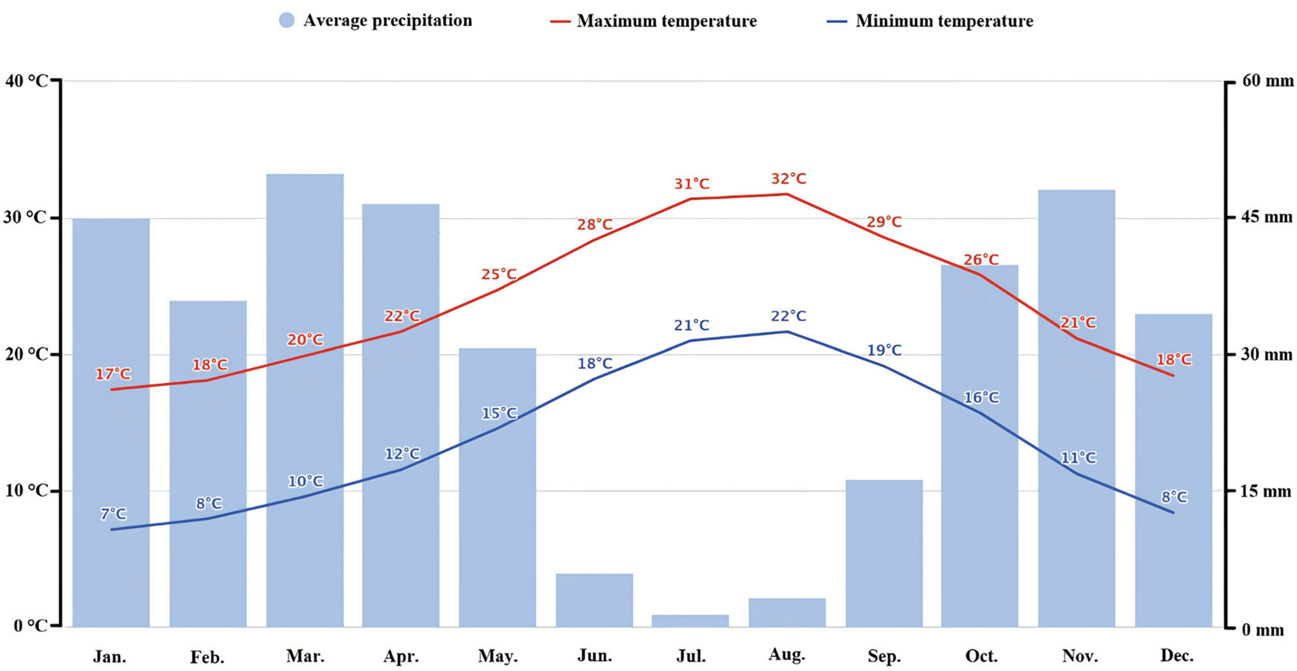

Fig. 2. Main characteristics of the weather conditions of the study area during 2023

For identification we use several taxonomic keys.(Bouché, 1972; Cuendet, 2001; DP Schwert, 1990; Edwards and Arancon, 2022; Hoffmann A, 1950, 1958; Jamieson, 1988; Kerney et al., 1983; Reynolds, 1977; Sims and Gerard, 1985; Tempčre and Péricart, 1989; Vandel, 1960, 1962).

2.3. Litter and soil properties characterizations

Environmental characterizations are also carried out in conjunction with soil macrofauna sampling at each sampling site. This involves determining the biomass (g/m^2) of invasive weed. In short, after these plant species around each sampling point were harvested over an area of $1m^2$, they were dried at 60°C for 48 hrs. The mass and gravimetric water content are also characterized for the litter, shortly after harvesting, the litter collected was dried at 60°C to estimate its mass (g/m^2), and at 105°C to determine their gravimetric water content (% of dry mass). Finally, to determine the gravimetric water content of the soil samples were taken to a depth of 12 cm, then dried at 105°C. For the characterization of the chemical properties of the soil, samples were taken from a depth of 0–30cm, and then air-dried, crushed and sieved at 2 mm. The analysis of physicochemical parameters, such as pH was determined using a pH meter. The cation exchange capacity (CEC) was determined by the sodium acetate method (Chapman, 2016). Organic matter (OM) was quantified using the Walkley-Black method (Walkley and Black, 1934). Assimilable phosphorus (P) was determined via the OLSEN method, which uses 0.5M sodium bicarbonate ($NaHCO_3$) at pH=8.5 (Olsen, 1954). Assimilable potassium (K^+) is determined via extraction with a neutral, normal solution of ammonium acetate, followed by determination with a flame photometer SHERWOOD® as described by Mathieu et al. (Mathieu et al., 2003). The electrical conductivity (CE) was measured using an electrical conductivity meter. Finally, sodium content was determined by atomic absorption and a flame photometer SHERWOOD®.

2.4. Diversity of soil macrofauna

Soil macrofauna diversity for each sampling site of the two agricultural systems was calculated via data from two complementary collection methods (TSBF method and pitfall traps), and quantified using various diversity indices (specific richness, which is defined as the number of different classes present in the studied system, the Pielou evenness index (1) (Pielou, 1969) and the Shannon–Wiener index (2) (Shannon, 1948)), which were calculated using the following formulas:

Equation (1): $E = \frac{H'}{\ln S}$

Equation (2): $H' = -\sum_{i=1}^{n} P_i ln\, P_i$

Where, P_i is the ratio of the number of individuals of a given species (Ni) to the total number of individuals (N); S is the total number of species identified. To estimate abundance and biomass, we used data from only the TSBF method. Abundance is expressed as the total number of individuals of a species in a defined area of one square meter. The biomass ($mg.m^{-2}$), which is expressed as fresh mass per area of one square meter, all specimens collected in the field were sorted and weighed individually in the field to be transported to the laboratory for identification.

2.5. Statistical analysis

Data normality was assessed using the Shapiro-Wilk test, and the Levene test to verify the homogeneity of variance. Before performing the analysis, the data of the soil macrofauna, were classified into 5 taxonomic groups (for one-way ANOVA) and 8 groups (for PCA and RDA), to minimize the complexity of reading the figure, by reducing the number of variables. Then, we performed a one-way analysis of variance (ANOVA) and a Tukey's HSD test, to identify the significance of differences in the diversity indices, abundance and biomass of soil macrofauna among the two agricultural systems, using the average value of a set of 15 sampling site points in each management system. Pearson's correlation analysis was employed to determine correlations between soil macrofauna diversity and edaphic variables across sugar beets in different agricultural systems. To evaluate the effects of soil management practices on the composition of the soil macrofauna communities, litter and soil properties, a principal component analysis (PCA) was conducted. Prior to analysis, the data of soil macrofauna abundance (ind. m^2), were transformed by log (x +1) to reduce the effects of dominant taxonomic groups. Additionally, redundancy analyses (RDA) was used to analyze the influences of litter and soil property variables on the macroinvertebrate communities. The soil faunal abundance and edaphic properties are transformed (method «hellinger») and standardized (method «standardize») respectively. All the statistical analyses in this study were conducted via R software (v4.3.2) in R Studio (v12.0.369; R Studio Team 2023).

3. Results

3.1. Effects of management systems on soil macrofauna abundance and biomass

Overall, the abundances of the soil fauna communities were higher in the organic system (780 ±190 $individuals.m^{-2}$) than in the conventional farming system (296 ±69 individuals. m^{-2}) (Table S1). Isopods, insects and earthworms are the most representative groups in both agricultural systems (Fig. 3). However, the transition to the organic farming system showed remarkable variation on soil macrofauna community (Fig. 3). For example, Isopods abundance was more than 2.5 times higher under organic farming, whereas for the other groups, the abundance is also nearly doubled under organic farming. According to the PCA (Fig. 6), the impact of agriculture systems on the macrofauna of soil was significant. The Dim1 showed that Diplopoda, Isopoda, Hymenoptera and Coleoptera were related to organic sugar beet. On the other hand, Dim2 indicated that Blattodea abundance was associated with conventional sugar beet (Fig. 6). In contrast, in terms of abundance, the biomass ($mg.m^{-2}$) of each taxonomic group of sugar beet soil macroinvertebrates,

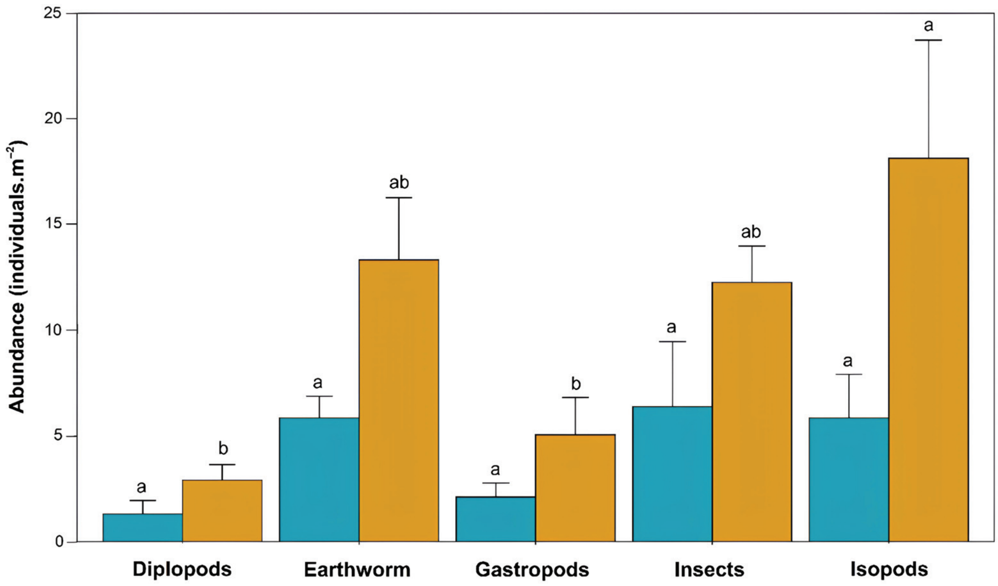

Fig. 3. Abundance (mean ± SE) of the soil macroinvertebrates of the sugar beet in the two agricultural systems (n=15 of each farming practice, organic and conventional farming, indicated by brown and blue colors respectively)

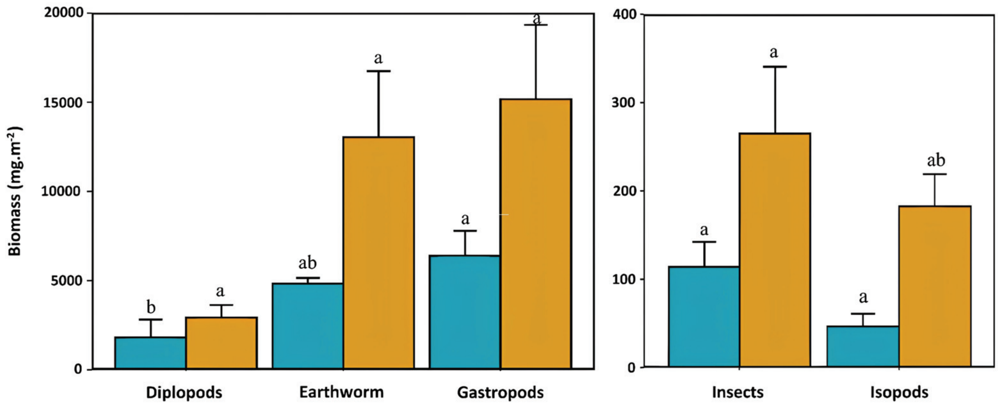

Fig. 4. Biomass (mean ± SE) of the soil macroinvertebrates of the sugar beet in the two agricultural systems (n=15 of each farming practice, organic and conventional farming, indicated by brown and blue colors respectively)

was increased almost in duplicate during the conversion from conventional to organic farming systems (Fig. 4).

3.2. Effects of management systems on soil macrofauna diversity

The soil macrofauna diversity was similar between the two different agricultural systems (Fig. 5). However, the results revealed that, the means of the specific richness, Pielou evenness and Shannon-Wiener index were not significantly different between the two farming systems (Fig. 5). This result was confirmed by PCA analysis (Fig. 6), which revealed that the two agricultural systems have common compositions of soil macrofauna with higher specific richness and abundance in organic farming system than in the other conventional farming systems. According to result of the Pearson correla-

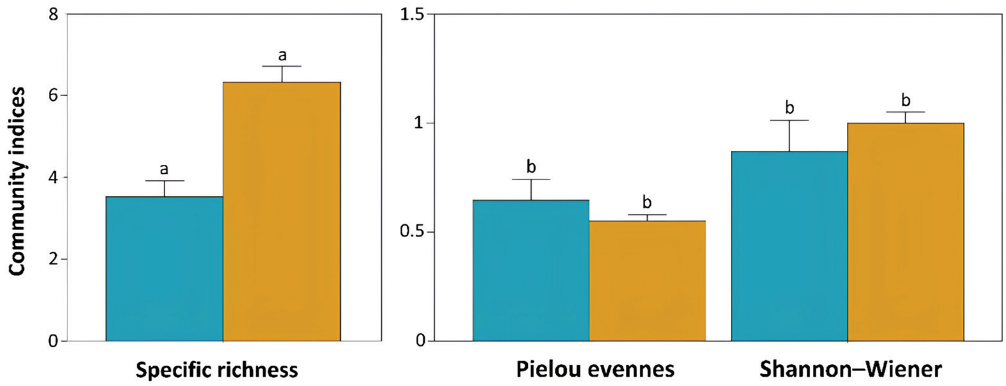

Fig. 5. Diversity (mean ± SE) of the soil macroinvertebrates of the sugar beet in the two agricultural systems (Calculation of each index was done at the site scale. n=15 for each farming practice, organic and conventional farming, indicated by brown and blue colors respectively)

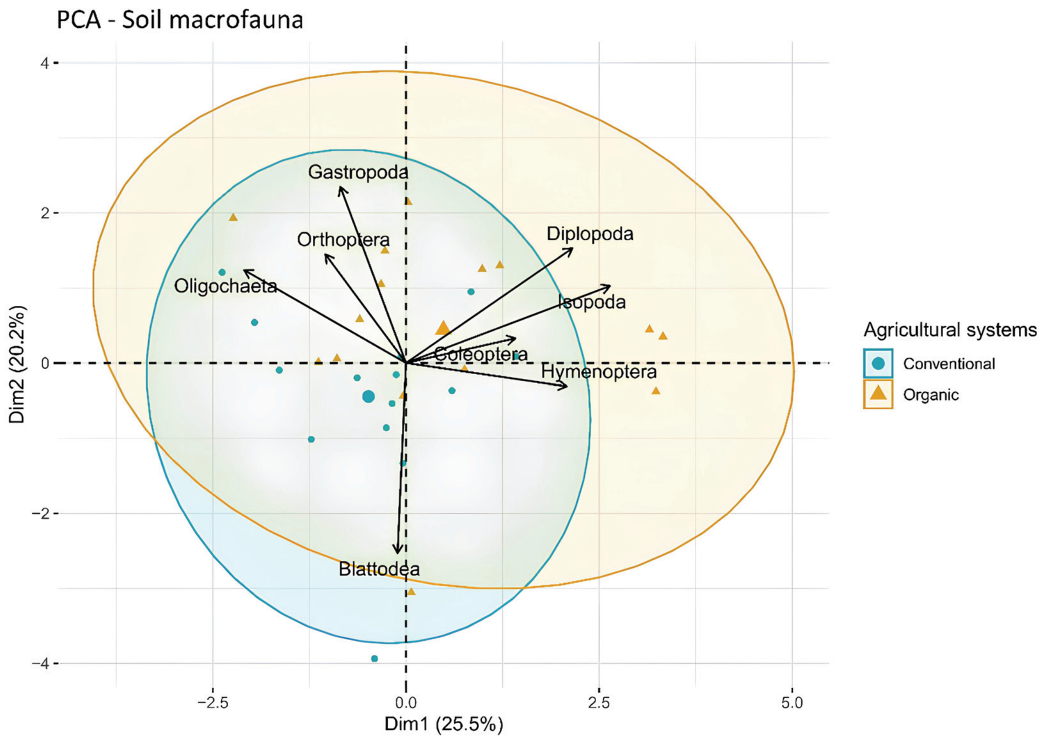

Fig. 6. Results of principal component analysis (PCA) of soil macrofauna and the sampling points according to agricultural systems (organic and conventional practices) from Berkane, North East region of Morocco. The dots and triangles on the graph represent a sample of soil from two agricultural systems

tion analysis between the soil macrofauna diversity, the litter and soil variables (Table 1), the specific richness was strongly positively correlated with Potassium, weed biomass ($p < 0.05$) and Lgwc ($p < 0.01$), whereas was strongly negatively correlated with Sgwc ($p < 0.05$). The Shannon-Wiener index was negatively correlated with pH and Sgwc ($p < 0.01$). Additionally, Pielou evenness was negatively correlated with soil pH ($p < 0.05$).

Table 1
Pearson's correlation analysis between soil macrofauna diversity, litter and soil properties across the sugar beet in different agricultural systems. pH: potential of hydrogen. OM: organic matter. CEC: cation exchange capacity. CE: electrical conductivity. Sgwc: soil gravimetric water content. Lgwc: Litter gravimetric water content.

Litter and soil properties	Indices		
	Specific richness	Shannon Wiener	Pielou evenness
pH	0.158	**–0.343***	**–0.427****
Potassium	**0.458****	0.285	0.049
Phosphorus	0.046	0.010	0.104
Sodium	–0.188	0.003	0.112
OM	0.173	0.240	0.197
CE	0.268	–0.064	–0.288
CEC	0.164	0.103	0.041
Weed biomass	**0.629****	0.223	–0.039
Litter mass	0.257	–0.061	–0.090
Lgwc	**0.396***	0.189	0.026
Sgwc	**–0.449****	**–0.383***	–0.230

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

3.3. Effects of management systems on habitat variables

According to the PCA results (Fig. 7), the two farming systems (conventional and organic) have different chemical profiles, as well as significant effects on some soil edaphic properties. A total of 11 habitat variables were assessed, of which five were assigned a relatively high level of significance ($p < 0.05$) between the two farming systems (Table 2), such as, the pH ($p=0.001$), Potassium content ($p=0.001$), Weed biomass ($p=0.0001$), Litter mass ($p=0.014$) and Litter gravimetric water

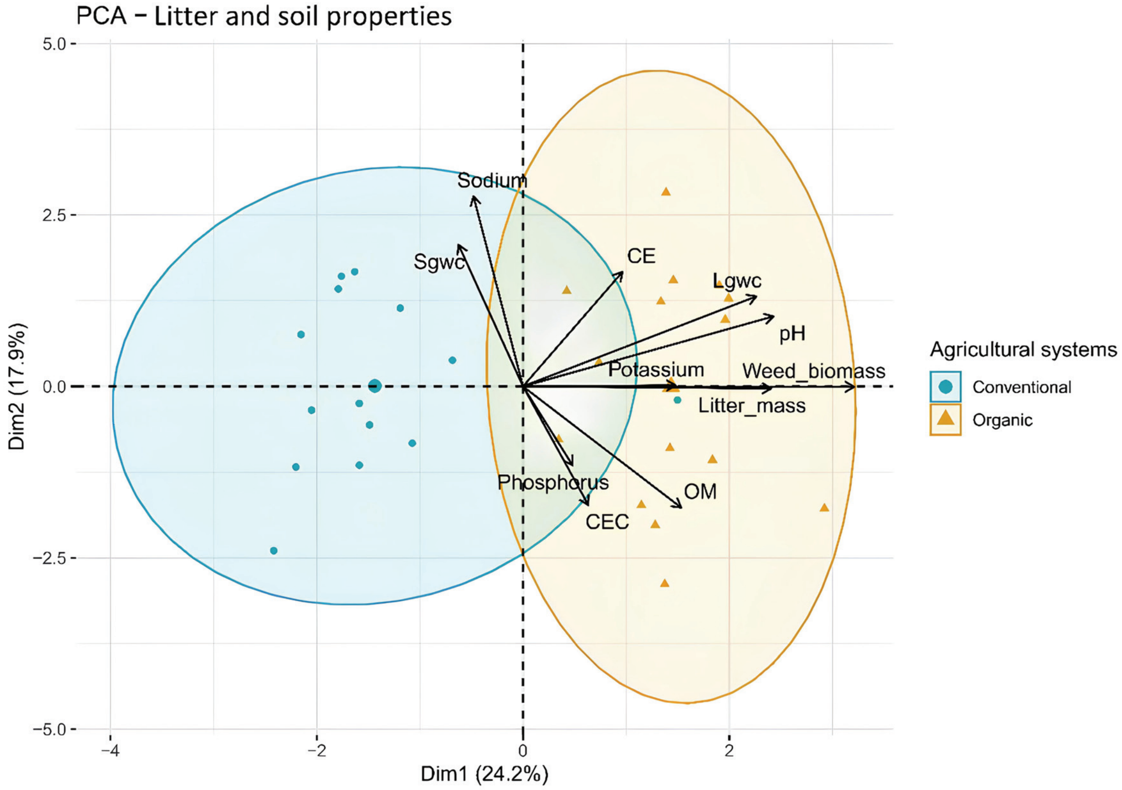

Fig. 7. Results of principal component analysis (PCA) for litter and soil properties and the sampling points according to management practices from Berkane, North East region of Morocco. pH: potential of hydrogen. OM: organic matter. CEC: cation exchange capacity. CE: electrical conductivity. Sgws: soil gravimetric water content. Lgwc: Litter gravimetric water content. The dots and triangles on the graph represent a sample of soil from the two agricultural systems

Table 2
Habitat variables (mean ± SE) under two soil agricultural systems. The mean values of the variables were calculated from the average values on each sampling site (n = 15 for organic farming and n = 15 for conventional farming). pH: potential of hydrogen; OM: organic matter; CEC: cation exchange capacity; CE: electrical conductivity; Sgwc: soil gravimetric water content; Lgwc: Litter gravimetric water content.

Habitats variables	Farming system		
	Organic	Conventional	*p*-value
pH	7.13 ± 0.024	6.18 ± 0.248	**0.001**
Potassium	0.84 ± 0.051	0.55 ± 0.062	**0.001**
Phosphorus	67.50 ± 5.144	64.01 ± 6.464	0.675
Sodium	0.61 ± 0.068	0.67 ± 0.053	0.484
OM	2.07 ± 0.332	1.53 ± 0.149	0.151
CE	0.48 ± 0.063	0.35 ± 0.041	0.092
CEC	22.44 ± 2.035	18.89 ± 1.262	0.148
Weed biomass	36.74 ± 1.057	17.02 ± 1.925	**0.000**
Litter mass	18.32 ± 1.348	12.72 ± 1.649	**0.014**
Lgwc	27.05 ± 2.691	16.43 ± 2.238	**0.005**
Sgwc	5.12 ± 0.536	6.20 ± 0.892	0.307

content (p=0.005) were significantly higher in the organic system than in the conventional farming system. However, the other variables of the soil such as Phosphorus, Sodium, organic matter (OM), CE, CEC, and content of soil gravimetric water content (Sgwc) were less influenced, and no statistically significant impacts of management practices were observed ($p > 0.05$). The PCA explained 42.1% of the variability in the habitat variables with the first two axes (Fig. 7). Axis 1 revealed that the highest contents of weed biomass, OM, litter mass, pH, Lgwc and Potassium were associated with the plots of organic farming practices (Fig. 7). On the other hand, axis 2 indicated that the contents of Sodium and Sgwc were associated with conventional farming practices.

3.4. Effects of litter and soil properties on macrofauna communities

The correlations between the macrofauna of soil in association with litter and soil properties are shown in Figure S1. On the basis of the RDA results, the edaphic variables measured explained 36.93% of the variation in the soil macrofauna composition. RDA1 and RDA2 explained 13.65% and 8.5% respectively of the total variation (Fig. S1). On the basis of these results, the sites (blue circles) are globally similar and the different groups of soil macrofauna have different significant relationships with all variables studied. Some species such as Blattodea and Isopoda stand out from the group, which means that they do not occupy many sites in common with other groups. Among the edaphic variables, Potassium and Lgwc have strong effects on soil macrofauna. Blattodea has negative relationships with CEC and Sodium ($p < 0.05$), because arrows are in opposite directions to these variables. On the other hand, positive correlations were observed between Coleoptera and Potassium, Lgwc and weed biomass ($p < 0.05$). Additionally, Oligochaeta and Diplopoda were highly correlated with OM and litter mass.

4. Discussion

The present study contributes to the first characterization and knowledge of the soil invertebrate communities of Mediterranean agroecosystems. Despite its ecological biodiversity and diversification of its natural environment, the soil macrofauna of plots studied in the province of Berkane remains unidentified and largely unknown. Importantly, this study is the first to examine the biological measurements of agricultural soils in this region, according to our literature research.

Soil organisms play crucial roles in soil dynamics and the provision of ecosystem services. Owing to their ecological roles, there are generally two main functional categories of soil macrofauna in this study. The first group includes organisms that contribute to the availability of nutrients for other organisms, modify the physicochemical properties of the soil, and are called ecosystem engineers such as earthworms (Jouquet et al., 2006). The second group includes Diplopoda and Isopoda. These organisms physically alter the soil environment, fragment and mix the litter (Lavelle et al., 1993, 1994) According to Lavelle et al. (2004), the composition, biomass and abundance of soil macrofauna are related to the environmental conditions, management practices, properties and vegetation cover of the soil. The levels of different litter and soil properties in the organic farming system were significantly greater than those in the conventional farming system (Table 2). This result may be related to the use of phytosanitary products, which reduce the number of taxa and therefore the key functions that they exert in soil ecosystems. Their distribution has a significant impact on nutrient cycling and stabilization in ecosystems (Marina et al., 2018). Regarding litter availability, the organic farming system is characterized by a high amount of moisture present in the litter, which may have been a contributing factor to the increased abundance and biomass of earthworms. Similar observations have been reported in various land use systems (Bartz et al., 2013; Suntoro et al., 2023). The quantity of OM differs among the different agricultural systems. The difference in litter quantity may be the most important factor contributing to the change in the diversity and density of macrofauna, by providing them availability of nutriments sources and enabling favorable habitat conditions (Cole et al., 2006; Yin et al., 2018). Weed biomass, litter mass and water content, are significantly higher under organic system than under conventional farming systems, thus the use of herbicides can change habitat conditions, and affect the edaphic properties of soil. The soil fauna composition is strongly correlated with the physicochemical properties of its habitat (Begum et al., 2013; Frouz et al., 2011). In this study, the litter and soil properties were changed from conventional to organic fields, except for sodium and soil gravimetric water content (Sgwc), this difference in habitat conditions affects the richness and abundance of soil macrofauna. The abundance of the soil macrofauna communities in the organic system was higher than that in the conventional farming system which is in accordance with the findings of a similar study (Yang et al., 2021), and could be influenced by changes in the quality of the soil properties and litter. Soil properties can be affected by various land use types, which can affect the soil faunal density (Ali et al., 2019; Jiménez-Carmona et al., 2020; Shultz et al., 2006; Zhang et al., 2015) and diversity (Uvarov et al., 2011). For example, the abundance of earthworms is significantly correlated with soil fertility (Bartz et al., 2013). Some herbicides do not specifically target soil fauna, but the intensive use of these products in crops could have a significant impact on the soil fauna community (Ibrahim, 1984; Nachimuthu et al., 2016). The toxicity of herbicides based of glyphosate which are widely used in sugar beet fields in conventional systems, have been studied for earthworms in laboratory tests (Correia and Moreira, 2010). Additionally, the impact of pesticides on earthworms has been studied, and the results revealed a negative effect on their abundance and biomass (Pelosi et al., 2014). In addition, little is known about how amalgams of several herbicides can impact soil fauna in the field (Kortenkamp et al., 2009; Relyea, 2009). Feedback to agricultural systems varies according to soil species. For example, earthworms, gastropods and isopods were mostly affected, which may be due to the physiological characteristics of these species, such as mobility, bioaccumulation and biomagnification. Unlike several studies, which have shown, that diplopods have a low response to herbicide toxicity (da Silva Souza et al., 2014; Henneron et al., 2015; Paoletti et al., 1995). Similarly, our results show that diplopods are significantly affected by changes of agricultural systems. The increase in the diversity of soil fauna is also linked to the higher disponibility of nutrients resources from plant residues (Heinze et al., 2010; Siepel, 1996), which can explain the slight increase in specific richness in organic farming than in conventional farming. Our result show that, were no changes have been seen in the diversity indices between the two farming systems. If the change in biodiversity is influenced by agricultural practices (Hole et al., 2005), it is also strongly limited by several external factors such as, the variety of habitats that surround the ecosystem, and the percentage of uncultivated land (Bengtsson et al., 2005; Tscharntke et al., 2002). The mosaic landscape around the study area, can explain why sugar beet fields under conventional agricultural system are well diversified, and why there are no significant differences between the two farming systems. This could also be due to the short transition period, which did not allow new species to settle in the fields.

The results of this study demonstrated that organic management practices have significant effects on the abundance and biomass of soil macrofauna communities, and improve litter and soil property quality. In addition, soil macrofauna can have a positive impact on the decomposition of organic matter and its availability in the soil, the physical structure of the soil and the release of nutrients for plant growth (Frouz, 2013; Frouz et al., 2008; Roubíčková et al., 2009). Our study has shown that the transition to organic farming systems has a positive effect on the abundance and biomass of the soil macrofauna community, which is supported by previous studies ((Cole et al., 2006; Coulis, 2021; Henneron et al., 2015; Suárez et al., 2019).

Based on these results, our findings, could inform sustainable agricultural policies in Morocco, or similar regions by practically implement soil-friendly strategies, like diverse crop rotations, minimize phytosanitary products inputs by adopt integrated pest management, such the use biocontrol agents, monitor soil health by test soil periodically for key nutrients (NPK), and organic carbon.

5. Conclusions

The present study revealed that the transition from conventional cultivation into organic farming systems has a positive effect on soil macrofauna communities, thus contributing to changes in the litter and soil properties of sugar beet crops. However, the abundance and biomass of each taxonomic group of soil macrofauna increased almost in duplicate during the transition to the organic farming system. On the other hand, the diversity was similar between the two different agricultural systems, with a slight increase in specific richness in the organic farming system compared with the other conventional farming systems. Therefore, we assume that the use of phytosanitary products may have an indirect impact via changes in the habitat conditions of the soil fauna.

Conflict of interest

The authors declare no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Mourad Bendada – Conceptualization, Methodology, Formal analysis, Resources, Writing – original draft. Abderrahmane Hadini – Resources, Formal analysis. Youness Taarabt – Resources. Karim Andich – Conceptualization, Methodology. Khalid El Bekkaye – Writing – review and editing, Supervision. Khalid Chaabane – Supervision, Validation.

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