

Original Research Article

CODEN: PJZSAZ e-ISSN: 1331-7776

Seasonal and crop-type effects on ant diversity in Mediterranean fruit-tree agroecosystems (Northeastern Algeria)**Hayet Kerkache^{1*}, Lyes Aissat², Wafa Derdoukh³**¹Laboratory of Applied Zoology and Animal Ecophysiology, Faculty of Natural and Life Sciences, University of Béjaia, City of Béjaia, Bejaia, Algeria²Department of Biological and Environmental Sciences, Faculty of Natural and Life Sciences, University of Béjaia, City of Béjaia, Bejaia, Algeria³Department of Fundamental Education SNV, Faculty of Natural and Life Sciences, University of Jijel, Ouled Aissa, Jijel, Algeria***Correspondence:** Hayet Kerkache (hayet.kerkache@univ-bejaia.dz)**Article info:****Received:** 27 July 2026**Revised:** 23 September 2026**Accepted:** 24 September 2026**Available online:** 24 September 2026**Academic Editor:** Prof. Marina Piria, University of Zagreb Faculty of Agriculture, Croatia**How to Cite:**

Kerkache H., Aissat L., Derdoukh W. (2026). Seasonal and crop-type effects on ant diversity in Mediterranean fruit-tree agroecosystems (Northeastern Algeria). Agric Conspec Sci 91: e0017.

This article is an accepted manuscript and an uncorrected proof that has not undergone copyediting, language editing, or technical checks. The final version of the record may differ from this version.

ABSTRACT

Ants (Formicidae) play critical ecological roles in agroecosystems; however, their dynamics across various crops and seasons are still not well understood in Mediterranean fruit-tree landscapes of North Africa. This study examines the effects of crop type and seasons on ant diversity and community composition in the Soummam Valley's agroecosystems (Algeria). Pitfall traps were used to sample ant assemblages in citrus, fig, olive, and pear orchards over the winter, summer, and autumn seasons (2019-2020). 24 species were identified (16 genera, 4 subfamilies) and examined diversity patterns using GLM, NMDS, and PERMANOVA. Our findings demonstrate significant seasonal variation, with the highest species richness in summer and autumn compared to winter. Fig orchards showed the highest total diversity, whereas Pear orchards displayed the highest abundance but the lowest diversity, indicating substantial domination by a few species; however, because each crop type was represented by a single orchard, these differences cannot be attributed exclusively to crop type. In the PERMANOVA, neither crop type ($R^2 = 0.300$, $p = 0.294$) nor season ($R^2 = 0.272$, $p = 0.128$) significantly explained overall community composition (full additive model: $R^2 = 0.571$, $p = 0.175$), and a Crop $\times$ Season interaction was not tested. The NMDS showed extensive overlap among the seasonal assemblages (with more dispersed winter assemblages), which is compatible with a shared core of Mediterranean generalist species. These results provide baseline data on ant assemblages in Algerian fruit-tree agroecosystems and highlight the need for replicated, orchard-level studies to assess how crop type and management affect ant-mediated ecosystem services such as natural pest control.

Keywords: Agroecosystems, Biodiversity, Myrmecology, Seasonality, Soummam Valley

INTRODUCTION

An agroecosystem is defined as an ecological system modified by human beings for the purpose of food production, fiber, or other agricultural products (Gliessman, 2016). Agriculture plays a significant role in rural development in Algeria and is regarded as one of the main drivers of the country's economy (Laoubi and Yamao, 2009). The Soummam valley is situated in Bejaia Wilaya, in northeast Algeria, where the cultivated land comprises 164,794 ha, with 60% of this area is exclusively designated to fruit tree cultivation (Kherbouche et al., 2012). The dominant tree crops are olive trees (50,662ha), fig trees (13,352 ha), and citrus trees (2,122 ha) (Kherbouche et al., 2012).

The heterogeneity of agricultural landscapes has a positive effect on regional biodiversity and ecosystem services (Folgarait, 1998; Parker and Kronauer, 2021). Loss of biodiversity affects ecosystem processes like nutrient cycling and seed dispersal by reducing species richness as well as functional diversity and evolutionary history (Brodie et al., 2021). The primary causes of biodiversity loss in agroecosystems are soil degradation, agrochemical use, habitat loss, water depletion, and agricultural intensification. These factors combine to fragment habitats and decrease genetic diversity that is essential for ecosystem services like pollination and pest control (Dudley and Alexander, 2017; Jing et al., 2025). Moreover, biodiversity loss threatens food security by reducing the diversity of species required for resilient food systems and ecosystem functions (Elouafi, 2024; Pilling et al., 2020), whereas compared to traditional monocropping systems, agroforestry systems that incorporate a variety of trees and crops can reduce biodiversity loss by increasing floral, faunal, and soil microbial diversity, thereby supporting the provision of ecosystem services (Santos et al., 2019; Udawatta et al., 2019).

In this regard, increasing awareness in agroecosystems should be given greater consideration in the context of biological conservation, given that some agroecosystems represent a repository of high pronounced biodiversity, including ants (Perfecto et al., 2007). Only, a few studies have been conducted on ant community composition within Mediterranean agroecosystems, for example: (Castellarini et al., 2024); (Zina et al., 2024). Nevertheless, Ant biodiversity in agroecosystems is still poorly studied, especially in Algeria.

Ants (Hymenoptera, Formicidae) are widely distributed, and represent the most dominant and highly diverse within terrestrial faunal groups. They represent up to half of the total insect biomass worldwide and exceed the combined biomass of all vertebrates in most terrestrial biomes (Andersen, 2021). They are the most diverse eusocial insects, with over than 13500 species classified into 334 genera and 17 subfamilies (Borowiec et al., 2021). Ants show many different and distinctive patterns of life, enabling them to interact with widely diverse animal and plant communities (Parker and Kronauer, 2021). Ants play a circular role in ecosystems as ecosystem engineers that are essential to preserving biodiversity and ecosystem functioning in a variety of habitats because of their diverse roles (Folgarait, 1998; Parker and Kronauer, 2021). They also have a significant impact on the composition of plant communities and agricultural productivity by affecting the rate of decomposition, controlling pests and dispersing seeds (Parr et al., 2016; Sankovitz et al., 2024). Nevertheless, the intensification of agricultural practices threatens the biodiversity of ants, which is essential for the provision of these services (Dauber and Wolters, 2004).

The Mediterranean region is known for its remarkable variety of ant species (Kass et al., 2022). In Mediterranean agroecosystems, ants can be useful ecological indicators because their

presence can reveal the impact of various land management practices (Castracani and Mori, 2006). However, in comparison to larger agroecological systems, the potential of agricultural landscapes in this area to sustain ant biodiversity has significantly decreased as a result of their intensification (Fonseca et al., 2021). Moreover, ant communities are greatly impacted by cultivation disturbances, so maintaining natural forests and a variety of agroforestry systems within agricultural landscapes is essential for maintaining ant diversity (Durot et al., 2023). Additionally, invasive ant species have catastrophic effects on native fauna through a numerous of mechanisms, including habitat disturbance, competition for resources, and limiting foraging activity (Siddiqui et al., 2021).

In order to acquire a deeper knowledge of the diversity of ants, particularly in agroecosystems, we examine the ant communities across four distinct crop types within the Soummam valley's agroecosystems, located in the northeast of Algeria. The aim of the study is to assess the effect of crops on ant biodiversity and examine these communities' seasonal variation. Two hypotheses were proposed: 1) The diversity of ants differs among the sampled crop orchards, possibly owing to the different microhabitats and resource availability provided by each crop (as each crop type was represented by a single orchard, this hypothesis can only be assessed descriptively, without independent replication). 2) Ant diversity varies significantly across the four crop types with seasons, as different crops may support different ant communities at different seasonal times. Obtained results from this work may enable better knowledge of the ant biodiversity in agroecosystems in the study area.

MATERIALS AND METHODS

Study area

The study area is situated in the Soummam Valley, in the north-east part of Algeria. It is interposed between the mountain ranges of the Djurdjura to the west and its extension to the north-east by the Aghbalou-Goraya range, and the Bibans to the south and their extension eastward by the Babors. From the south-western slopes of the Djurdjura mountain range [36° 21' N 3° 53'E] to the Mediterranean coast, east of Béjaia [36° 45' N 5° 20' E].

The valley is characterized by a Mediterranean climate, with a cool, wet season from October to April and a hot, dry season from May to October (Kherbouche et al., 2012). The climate in the lower part of the valley, situated between Sidi-Aich and Béjaïa, is sub-humid, with an annual rainfall ranging from 600 to 900 mm and a summer temperature in the range of 24–28°C. However, the upper valley, which is situated between Tazmalt and Sidi-Aich, is characterized by a semi-arid climate with an annual rainfall ranging from 400 to 600 mm (Kherbouche et al., 2012). Furthermore, the summer temperatures in this region are higher than those observed in the lower valley. The distribution of crops at the study sites is influenced by the two bioclimatic subtypes. This is due to the fact that orange trees require more water than olive trees (Kherbouche et al., 2012).

Sampling sites

The sampling was carried out between 2019-2020 for three seasons (winter, summer, and autumn) in two agroecosystems in the Soummam Valley (Fig. 1), including ITAF (National

Institute of Fruit Trees and Vine) and El Kseur. The agricultural management practices suited to different sectors, such as tillage, irrigation, and chemical applications, are presented in Table 1.

The ITAF station [36°34'48.28"N 4°40'4.90"E] is located in the Takerietz commune. The study was conducted on two fields of fig (*Ficus carica* (Linnaeus, 1753)) and olive (*Olea europaea* (Linnaeus, 1753)) trees, where the inter-rows feature an understory of spontaneous herbaceous vegetation, including *Avena fatua* (Linnaeus, 1753), *Bromus sterilis* (Linnaeus, 1753), *Sinapis alba* (Linnaeus, 1753), *Oxalis pes-caprae* (Linnaeus, 1753), *Lolium perenne* (Linnaeus, 1753), and *Anthemis arvensis* (Linnaeus, 1753). It should be noted that the plots are surrounded and separated by the windbreaks of *Cupressus sempervirens* (Linnaeus, 1753).

At El Kseur station [36°40'36.07"N 4°52'46.46"E], the study was carried out in two types of cultures, that of citrus (*Citrus sinensis* (Osbeck, 1765)) and pear cultivation (*Pyrus communis* (Linnaeus, 1753)), where the citrus trees are interspersed with the dominant weed *O. pes-caprae* and a few individuals of *Malva sylvestris* (Linnaeus, 1753). Pear trees are interspersed with weeds, including *A. fatua*, *O. pes-caprae*, and *S. alba*.

Because each crop type was represented by a single orchard (fig and olive at ITAF; citrus and pear at El Kseur), crop effects could not be replicated independently. Crop identity is therefore confounded with orchard identity and, partly, with station (ITAF vs El Kseur). Consequently, the observed differences among orchards must be interpreted with caution, as they may reflect crop type as well as environmental and management characteristics specific to each site. Orchard characteristics (area, tree age) and management practices (tillage, irrigation, pesticide use) were not quantified.

Ant sampling

Ant assemblages were surveyed using pitfall traps designed to capture epigeic and mobile species. In each agroecosystem, eleven pitfall traps were installed along a linear transect of 50 m, maintaining a spacing of 5 m between consecutive traps. The traps consisted of plastic cups (102 ml; 12 cm in height and 10 cm in diameter) inserted into the soil so that the rim was level with the ground surface. Each cup was filled to approximately three-quarters with a solution of propylene glycol used as a preservative, together with a few drops of detergent to reduce surface tension. Traps were left active in the field for 3 days before collection. Sampling covered three seasons over nine months (winter: December–February; summer: June–August; autumn: September–November), with two sampling expeditions per month (18 sampling events). During the COVID-19 pandemic (2019–2020), however, access to the study sites was limited and surveys in spring could not be carried out. Because spring samples are lacking, the dataset describes only part of the annual cycle (winter, summer and autumn). The activity of ants in the Mediterranean fluctuates across the year. Many species are active throughout summer and fall when temperatures are favourable, although relatively mild winters permit the presence of cold-tolerant or opportunistic species. Sampling in these seasons thus spans a wide range of thermal conditions and gives a partial but informative perspective of the local ant fauna. Importantly, the exact same orchards were sampled repeatedly across the three seasons. Because individual crop types were not independently replicated across multiple distinct sites and repeated sampling occurred within the same orchards, this repeated sampling structure could not be formally integrated into the statistical models as random components due to sample size constraints at the pooled line level; this represents a

methodological limitation of the study, and differences between crops must be interpreted with caution as they may partly reflect orchard- or site-specific conditions.

Identification of ants

Collected specimens were sorted and identified to species level using the taxonomic keys developed by (Cagniant, 2006, 2005, 1997, 1996a, 1996b; Cagniant et al., 2020) and additional identification resources including (Barech et al., 2017), (Seifert, 2022, 2020, 2017, 2016a, 2016b, 1992), and the revisions provided by (Schifani et al., 2022) and (Schifani and Alicata, 2023). All identified specimens were deposited in the Applied Zoology and Ecophysiology Laboratory, University of Béjaïa.

Statistical analysis

Community diversity was determined using the Shannon diversity index (H') and Pielou's evenness index (E). The Shannon index was calculated as $H' = - \sum (P_i \log P_i)$, where P_i is the relative abundance of each species in relation to the total number of individuals observed (N). Evenness was then calculated using the ratio $E = H' / \log_2 S$, where S indicates species richness (Magurran, 2004). Evenness values range between 0 and 1, and the larger the value, the more evenly distributed the number of individuals is among species. Small values indicate dominance by a limited number of species (Barbault, 1981). Simpson diversity was calculated as $1 - D$, where $D = \sum p_i^2$.

Generalized linear models (GLMs) were used to test for differences in diversity metrics among orchards and seasons. The effective sampling unit across all statistical analyses was the pooled pitfall-trap line per orchard per season ($n = 12$ sampling units, derived from the cross-

classification of four crops and three seasons; the values of these sampling units are given in Supplementary Table S2). Because of this small sample size, and to prevent model saturation and the loss of residual degrees of freedom, additive models (Crop + Season) were fitted; interaction terms were not included, so a Crop $\times$ Season interaction was not tested. The error distribution and link function were specified for each response variable as follows: (i) species richness, quasi-Poisson distribution with a log link, the dispersion parameter being estimated from the data ($\phi = 0.94$, i.e., no evidence of overdispersion); the model is therefore practically equivalent to a Poisson GLM, with inference based on 6 residual degrees of freedom t-tests for individual coefficients, together with an F-test for the overall effect of season (Table 4); (ii) total abundance, negative binomial distribution with a log link to correct for overdispersion in the count data (Stoklosa et al., 2022); and (iii) Shannon diversity (H'), Simpson diversity ($1 - D$) and Pielou's evenness (E), Gaussian distribution with an identity link, used for simplicity although these indices are bounded (0–1 for E and $1 - D$), so that their estimates are interpreted cautiously given the small sample size. Estimates, standard errors, test statistics and p-values are reported in Table 4 for species richness and in Supplementary Table S1 for the other response variables. Reference levels were Citrus (crop) and Autumn (season) in Table 4, and Citrus and Winter, respectively, in Table S1. Random variance components (e.g., a 'Sampling Site' effect) could not be estimated from this saturated design. Moreover, because the three seasons were sampled in the same orchard, the sampling units are not fully independent (repeated measures at the orchard level); this dependence could not be modelled with a random effect, and p-values should therefore be regarded as approximate. Because each crop type was represented by a single orchard, crop effects were not independently replicated and are confounded with orchard- and site-specific conditions (see Sampling sites).

Venn diagrams were used to show shared and unique taxa between orchards and seasons (Yang et al., 2024).

Relationships among the five response variables (species richness, abundance, Shannon, Simpson and evenness) were assessed with Pearson product-moment correlations computed across the 12 sampling units (crop $\times$ season; $n = 12$, $df = 10$). Two-sided p-values are reported as exact values, without correction for multiple testing (a Bonferroni-adjusted threshold of $\alpha = 0.005$ for the ten tests is also given in the Results), and the correlations are interpreted descriptively because Shannon, Simpson and evenness are derived from the same relative abundances. The resulting correlation matrix was visualized with the *performance* program (Lüdecke et al., 2021). Patterns in ant assemblage composition were explored using non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity using the *vegan* package (Oksanen et al., 2013). Prior to multivariate analyses, species abundance data were Hellinger-transformed using the *decostand* function in *vegan*, a pre-treatment that down-weights the influence of numerically dominant species (e.g., *Messor barbarus* (Linnaeus, 1767)) and enhances the ecological realism of ordination and distance-based tests (Legendre and Gallagher 2001). An additive PERMANOVA model (Crop + Season) was used to assess main effects while retaining adequate residual degrees of freedom for permutation testing, strictly excluding any interaction term (Crop $\times$ Season). Given the small number of sampling units ($n = 12$), the statistical power of this test is limited. PERMANOVA is also sensitive to differences in multivariate dispersion, which was not tested separately. We also used an Indicator Species Analysis (IndVal) with the *multipatt* function in the *indicspecies* package to identify ant species that were significantly associated with particular crops or crop groups (p-values not adjusted for the 24 species tested) (De Cáceres and Legendre 2009). To examine

differences in community composition between orchards and seasons, we utilised adonis2 (permutational multivariate analysis of variance). If significant effects were found, pairwise comparisons were carried out using the pairwise.adonis function in the *pairwiseAdonis* package (Martinez Arbizu, 2020). As no significant effect of crop type or season was detected, no pairwise comparison was performed.

RESULTS

Faunal composition and inventory

The study of the myrmecofauna of Soummam Valley's agroecosystems in Bejaia allowed us to identify twenty-four species belonging to sixteen genera and four subfamilies: Myrmicinae, Formicinae, Dolichoderinae, and Ponerinae. The taxonomic distribution and abundance of these species across the four orchard types are detailed in Table 2.

Sampling effort and rarefaction

The sampling effort was sufficient to characterize the sampled ant fauna for each crop type. Rarefaction analysis showed that the small difference between the observed and estimated richness reflected that our sampling effort had captured almost the entire diversity of the ant community: extrapolation to twice the observed number of individuals added only about one to two species per crop type, although the curves had not fully levelled off and the confidence intervals were wide (Fig. 2). Estimated sample coverage was between 99.6% and 99.9% in all four orchards.

Ant community diversity by orchard type

Ant community diversity profiles varied markedly across the four agroecosystems (Table 3). Fig orchards (FG) exhibited the highest overall diversity and equity, with a Shannon index (H') of 2.08, an exact Simpson's diversity index (1-D) of 0.83, and a Pielou's evenness (E) of 0.72, indicating a comparatively well-balanced and species-rich assemblage. Conversely, pear orchards (PR) had the highest overall abundance (2,035 individuals), but the lowest diversity indices across all monitored systems ($H' = 0.81$, 1-D = 0.36, $E = 0.33$), yet 12 species were recorded. This contrast points to strong dominance by a few numerically abundant taxa, chiefly *M. barbarus* (1,612 of 2,035 individuals), which is reflected in the low evenness. Citrus (CTS) and olive (OLV) orchards displayed intermediate and comparable diversity structures; Citrus supported 15 species ($N = 1,204$, $H' = 1.25$, $E = 0.46$, 1-D = 0.52), while Olive supported 17 species ($N = 798$, $H' = 1.35$, $E = 0.46$, 1-D = 0.59). These orchard-level values are descriptive: each crop type was represented by a single orchard, so the differences cannot be attributed exclusively to crop type.

Seasonality and statistical modeling

The GLM showed a seasonal pattern in species richness (Table 4). The overall test indicated a significant effect of season on species richness ($F(2, 6) = 10.32$, $p = 0.011$). Relative to autumn (the reference level in Table 4), species richness was significantly lower in winter ($\beta = -0.968$, $SE = 0.261$, $t = -3.71$, $p = 0.010$). Exponentiating these coefficients into rate ratios showed that species richness was about 2.7 times higher in summer (rate ratio = 2.74) and 2.6 times higher in autumn (rate ratio = 2.63) than in winter. Interestingly, almost no statistical difference emerged between

the two warmer periods ($\beta = 0.039$, $t = 0.20$, $p = 0.845$, rate ratio = 1.04). Species richness in summer was thus similar to that in autumn, and both were higher than in winter.

To assess the multivariate effect of habitat and season on community composition, we performed a PERMANOVA on Hellinger-transformed data (Table 5). Neither crop type ($Df = 3$, $R^2 = 0.300$, $F = 1.398$, $p = 0.294$) nor season ($Df = 2$, $R^2 = 0.272$, $F = 1.908$, $p = 0.128$) had a statistically significant effect on overall community composition, and the full additive model was not significant either ($Df = 5$, $R^2 = 0.571$, $F = 1.600$, $p = 0.175$; Table 5). The proportion of variance associated with the model is therefore descriptive only, and the statistical power of the test is low with 12 sampling units.

Univariate GLMs for the remaining response variables (Table S1) indicated that, relative to citrus (the reference crop), the pear orchard had significantly higher total abundance (coefficient = 1.06, $p = 0.014$) and borderline lower Shannon diversity (coefficient = -0.72 , $p = 0.050$), with marginally lower Simpson diversity (coefficient = -0.26 , $p = 0.065$) and evenness (coefficient = -0.21 , $p = 0.083$). The fig and olive orchards did not differ significantly from the citrus orchard for any metric. Seasonal effects were more marked: relative to winter, both summer and autumn were associated with higher species richness (Table 4) and total abundance (coefficients = 2.93 and 1.42, respectively; both $p < 0.001$). Summer had a significant negative effect on evenness (coefficient = -0.29 , $p = 0.017$), which may indicate that assemblages become less even during this period of peak activity, when dominant species proliferate. Autumn was the only season that significantly increased Shannon diversity (coefficient = 0.73, $p = 0.028$), whereas no season had a significant effect on Simpson diversity (Table S1). Because each crop type was represented by a single orchard, crop-related patterns cannot be separated from orchard-specific effects.

Pearson correlations among the five response variables were computed across the 12 sampling units (crop $\times$ season; $n = 12$, $df = 10$; Fig. 3). Shannon and Simpson diversity were very strongly correlated ($r = 0.95$, $p < 0.001$), and both were positively correlated with evenness ($r = 0.60$, $p = 0.040$ and $r = 0.78$, $p = 0.003$, respectively); as these indices are derived from the same relative abundances, such correlations are expected. Species richness was positively correlated with Shannon diversity ($r = 0.65$, $p = 0.023$) but not significantly with Simpson diversity ($r = 0.46$, $p = 0.135$), evenness ($r = -0.16$, $p = 0.612$) or total abundance ($r = 0.39$, $p = 0.216$). Total abundance was negatively correlated with evenness ($r = -0.71$, $p = 0.009$) but not significantly with Shannon ($r = -0.27$, $p = 0.405$) or Simpson diversity ($r = -0.45$, $p = 0.137$), suggesting that the sampling units with the most individuals, dominated by a few species, were the least even. P-values are uncorrected; after Bonferroni correction for the ten tests ($\alpha = 0.005$), only the Shannon–Simpson and Simpson–evenness correlations remain significant.

The NMDS ordination (Fig. 4) has a stress value of 0.097 reflecting the reliability of the two-dimensional representation of the community structure. The 95% confidence ellipses (each based on four sampling units, one per crop) show overlap between all three seasons, with the greatest intersection between the autumn and summer clusters. This pattern of overlap of ellipses is consistent with the PERMANOVA results; the ordination reduces multivariate space to two dimensions and is sensitive to within-group dispersion, whereas PERMANOVA tests differences in centroid positions across all dimensions simultaneously (and is also sensitive to differences in dispersion, which was not tested separately). The NMDS ordination shows no clear separation of the assemblages by season, consistent with the absence of a significant seasonal effect in the PERMANOVA (Table 5).

The blue ellipse (winter communities) is the largest, reflecting the greatest dispersion among orchards in winter, when few individuals were captured, whereas summer and autumn points are more tightly grouped. The seasonal ellipses overlap extensively, with no clear separation, and points from the different orchards (CTS, FG, OLV, PR) are found in all seasonal ellipses; the seasonal tendencies visible in the ordination are therefore descriptive only and were not statistically confirmed by the PERMANOVA.

The Indicator Species Analysis (IndVal.g; Table 6) found just one significant indicator species, *M. barbarus*, associated with the combined crop group Citrus + Fig + Pear (Stat = 1.0, $p = 0.017$) because it was absent from the olive orchard (Table 2). This pattern may reflect characteristics of the olive orchard (e.g., open-soil conditions, reduced ground cover and low seed availability) that could act as a filter for this dominant harvester ant; however, because crop type was not independently replicated, orchard- or site-specific causes cannot be excluded. All other 23 species showed no significant indicator value ($p > 0.05$). Because 24 species were tested and the p -values were not adjusted for multiple testing, this single significant result should be regarded as exploratory.

Descriptively, species composition differed among the four orchards. For example, *M. barbarus* was highly abundant in the citrus and pear orchards, *Camponotus lateralis* (Olivier, 1792) was recorded only in the olive orchard, and *Camponotus foreli* (Emery, 1881) and *Camponotus piceus* (Leach, 1825) were recorded only in the pear orchard (Fig. 5).

DISCUSSION

In four cropping systems within the agroecosystems of the Soummam Valley, this study assessed the impact of various crops on ant biodiversity. 24 species of ants (Formicidae) were identified using pitfall traps, a method biased toward ground-active (epigeic) ants that likely underestimates arboreal and cryptic (hypogeic) species. Accordingly, the reported diversity represents the epigeic ant assemblage of the studied orchards rather than the entire ant community. Orchard type did not significantly affect ant community diversity, indicating that agroecosystem characteristics do not substantially influence community structure. Descriptively, the most diverse and even assemblage was found in the fig orchard, whereas the pear orchard had the highest abundance of ants but the lowest diversity and evenness, indicating that a few highly successful species dominated community structure; the citrus and olive orchards showed intermediate diversity patterns, with a slightly richer and more balanced assemblage in the olive orchard. In the univariate GLMs, however, crop-related effects were limited (significantly higher abundance and borderline lower Shannon diversity in the pear orchard than in the citrus orchard; Table S1), no crop effect was detected on species richness (Table 4), and neither crop type nor season significantly explained overall community composition (PERMANOVA; Table 5). As each crop type was represented by a single orchard, crop effects could not be replicated independently. Therefore, the differences observed among orchards must be interpreted with caution, as they may reflect crop type as well as environmental and management characteristics specific to each site. In the pear orchard, the highest abundance coincided with the lowest evenness and diversity, and across the 12 sampling units abundance was negatively correlated with evenness ($r = -0.71$; Fig.

3); in our data, high numerical abundance therefore did not translate into higher diversity, although this pattern cannot be attributed to crop type alone.

This found variation is consistent with the broader literature on Mediterranean agroecosystems, but the level of diversity is context-dependent. For example, in citrus fields in Catalonia, 14 ant species were detected (Cerdá et al., 2009). In contrast, studies conducted on agricultural landscapes in the Tagus and Sorraia river valleys in Portugal reported a much higher richness of 47 species, with ecological infrastructure patches supporting a more specialised and diverse community than the agricultural matrix itself (Zina et al., 2022). The most important influence seemed to be the intensity of management. Increased soil management in olive trees, particularly especially ploughing, was found to reduce ant species richness and functional diversity (Hevia et al., 2019). Likewise, 22 species are reported in Italian vineyards of the Adige Valley with few disturbance-tolerant taxa prevailing (Giannett et al., 2021). Conversely, complex natural systems such as the tidal marsh rice fields of Indonesia support unexpectedly high diversity (reported 43 species) that benefits from the abundance of aquatic and terrestrial nutrients these ecosystems provide (Ikhsan et al., 2020). The studies suggest that although agricultural expansion often reduces ant diversity and ecosystem function (Eisawi et al., 2022), the result depends on local habitat complexity and management. Compared to results obtained within different ecosystems in northeastern Algeria region, (Aissat, 2023) reported that ant community composition in Algerian islands is significantly different between islands of the regions Bejaia and Jijel, with three species contributing to 50.74% of the difference between islands. Also, Laakel et al. (2024) observed that suburban environments in Bejaia city (Algeria) have a more diversified ant community than urban settings with 19 species, 11 genera and 3 subfamilies. In Algerian arid steppes, Ant species

diversity and abundance shift significantly across the phenological stages of *Stipa tenacissima* (alfa), with distinct species dominating each plant phase (Khadoumi et al., 2025).

Seasonal variation significantly affected some univariate diversity metrics: species richness was significantly lower in winter than in summer and autumn (Table 3), and abundance, Shannon diversity and evenness also varied among seasons (Table S1). In contrast, neither crop type nor season significantly explained overall community composition in the PERMANOVA (Table 4), and the NMDS ordination shows no clear seasonal separation of the assemblages. In Mediterranean climes, thermal tolerance and seasonal shifts from cold, wet winters to hot, dry summers are important in modulating ant activity (Cros et al., 1997). In the present study, the highest diversity was recorded in the citrus orchard during summer months and the lowest diversity was recorded in the olive orchard during winter. Descriptive differences were observed among crop–season combinations; however, a Crop $\times$ Season interaction was not formally tested because the statistical models were additive. Seasonal effects on ant communities have also been reported in other biomes. In the Moroccan Argan forest, Keroumi et al. (2012) observed greater ant abundance and species richness during the dry season. In contrast, ant diversity in the Cerrado habitat decreases during the dry season (Queiroz et al., 2023). These patterns indicate the fundamental ways in which climatic seasonality influences ant communities, affecting everything from army ant reproductive timing (Tozetto et al., 2023) to ant-plant interaction peaks (Calixto et al., 2021). For example, the rainy season has a positive effect on the diversity of ants visiting plants and the composition of communities is affected by the structure of the vegetation in different seasons (Sampaio et al., 2023).

In the PERMANOVA, season and crop type together accounted for 57.1% of the variance in community composition, but neither term nor the full model was statistically significant. This lack of significance and the overlap observed in NMDS space are compatible with a shared taxonomic baseline among these agroecosystems, although the low statistical power associated with only 12 sampling units means that modest effects of crop type or season on community composition cannot be excluded. Whether assemblages change gradually, through subtle shifts in the relative abundance of core species, rather than abruptly, cannot be determined from the present data.

This high baseline overlap is a classic signature of Mediterranean tree crops and of semi-arid landscapes. These habitats generally harbour a hardy core of generalist or stress-tolerant ants that are well suited to both routine agricultural management and major seasonal swings. Importantly, the sampling design was saturated at the site level (one orchard per crop), so a formal random-effects estimate of site-level variance was not possible; crop and season were therefore modelled as fixed effects only. In addition, the three seasons were sampled in the same orchards (repeated measures), and PERMANOVA is sensitive to differences in multivariate dispersion (not tested here), so the p-values should be regarded as approximate. Several limitations must be acknowledged. As stated above, each crop type was represented by a single orchard, so crop effects cannot be separated from orchard- and site-specific conditions; orchard characteristics and management practices were not quantified. In addition, only three seasons (winter, summer and autumn) could be sampled, spring sampling having been prevented by COVID-19 restrictions, and the pooled trap-line per orchard and season provided only 12 sampling units, which limits statistical

power. Replicated orchards per crop type, sampled in all four seasons, are needed to separate crop effects from site effects.

Such patterns may be related to the thermal ecology of the leading taxa. The higher species richness and abundance in summer and autumn are consistent with a temperature-driven stimulation of foraging activity in these ectothermic insects. The lower evenness recorded in summer (Table S1) could reflect resource pulses (e.g., seed availability) favouring highly dominant, thermophilic harvester ants such as *M. barbarus*, and the higher Shannon diversity in autumn could reflect a relative decline of dominant taxa and increased activity of secondary taxa such as *Monomorium salomonis* (Linnaeus, 1758). However, species abundances were not analysed by season, no temperature or resource data were collected, and the PERMANOVA did not detect a significant seasonal change in composition; these explanations therefore remain hypotheses to be tested. Given that the notable limitation of this study is the absence of spring sampling, the season represents the primary period of ant activity, coinciding with favorable temperature and soil moisture conditions that stimulate foraging, colony growth, and reproductive flights in Mediterranean climates. This gap likely reduced detection probability for spring-restricted or thermophilic species, introducing a systematic bias in our richness and abundance estimates. As sampling completeness is necessarily linked to temporal coverage, the community metrics reported here likely represent a lower limit rather than a full inventory of the local ant community.

In addition to their importance as indicators of biodiversity, ants have considerable potential as biological control agents in agroecosystems. According to Anjos et al. (2022) and Lutinski et al. (2024), they can even increase crop yield, especially in perennial systems, by reducing plant

damage and suppressing populations of various insect pests. These ecological roles and their sensitivity to management were mirrored in the specific composition of the ant communities at our study sites. For instance, the harvester ant *M. barbarus*, which was highly abundant in the citrus and pear orchards because the seeds of weeds like *Avena fatua* served as a reliable food source (Platner et al., 2012); tillage intensity was not quantified. The predatory *Strumigenys membranifera* (Emery, 1869) was recorded only in the citrus orchard (two individuals), which is too few to support any inference about ecosystem stress or soil microfauna. *Tapinoma simrothi* (Krausse, 1911) was present in all four orchards, being most abundant in the fig orchard (326 individuals) and second in the pear orchard (228 individuals); aphid honeydew, if abundant in the pear orchard, could have supported this species, but this was not quantified.

Species dominance patterns also told an adaptation tale. The fig orchard was dominated by the heat-tolerant solitary forager *Cataglyphis bicolor* (Fabricius, 1793) with the arboreal *Crematogaster aubertii* (Emery, 1869) exploiting fig nectar suggesting a potential mutualism in which ants obtain food and may provide some defence to the tree. The olive orchard, possibly characterized by wide tree spacing, tillage and irrigation (not quantified), may have favoured the generalist *M. salomonis* which reached numerical dominance. Such conditions, if confirmed, may also have reduced the number of species, such as *Temnothorax recedens* (Nylander, 1856), that depend on the herbaceous cover and the diverse microhabitats destroyed by tilling. *Camponotus* species were represented by only a few individuals (*Camponotus thoracicus* (Fabricius, 1804), three, in the fig orchard; *C. foreli*, one, and *C. piceus*, two, in the pear orchard), so no inference on management effects can be drawn; the same applies to *Aphaenogaster mauritanica* (Dalla Torre, 1893) in the citrus orchard (nine individuals). These management-related explanations remain

hypotheses: management practices were not quantified and, because each crop was represented by a single orchard, crop effects cannot be separated from orchard-specific conditions.

Ants are known for their numerous useful advantages. Mediterranean species that feed on codling moth larvae, such as *Tapinoma magnum* (Mayr, 1861) and *Crematogaster scutellaris* (Olivier, 1792), directly reduce fruit damage (Schifani et al., 2023). Furthermore, *C. scutellaris* significantly affects pests like the brown marmorated stink bug (Castracani et al., 2017). Moreover, in citrus ecosystems, strong native ant communities which include species like *Lasius grandis* (Forel, 1909) and *Tapinoma nigerrimum* (Nylander, 1856) can serve as a biotic barrier against invasive ants like the Argentine ant (Zina et al., 2024). Additionally, ants protect fig trees from parasites and herbivores through protective mutualisms that increase fruit production (Jandér, 2015; Van Kolschoten et al., 2024). Ant chemical cues have the remarkable ability to prevent major pests such as the Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann, 1824)) from laying their eggs (Smargiassi et al., 2023). At the landscape level, controlling the amount of herbaceous cover in olive groves can increase the number of ants and the pressure they put on important pests like the olive moth and olive fly (Martínez-Núñez et al., 2021). Ants support strategies that depend on less insecticide spraying in pear orchards by reducing psyllid damage (Sanchez et al., 2021).

Seasonal variation significantly influenced some univariate diversity metrics, notably species richness, which was lower in winter, whereas neither crop type nor season significantly explained overall community composition in the PERMANOVA. Differences among orchards must be interpreted with caution, as each crop type was represented by a single orchard. These results provide baseline data on ant assemblages in four Mediterranean fruit-tree orchards of northeastern Algeria; they do not allow the effects of crop type or of agricultural intensification on

ant communities to be tested, which remains to be done in replicated orchards. Future studies should include several replicated orchards per crop type, quantify management practices and sample all seasons, and should focus on the development of agricultural practices that could preferentially favour beneficial ant species and their roles, while limiting unanticipated negative effects on the overall arthropod community.

CRedit AUTHORSHIP CONTRIBUTION STATEMENT

KERKACHE Hayet: Investigation, Methodology, identification of ants, writing, original draft;
AISSAT Lyes: Supervision, Methodology, software, Formal analysis; **DERDOUKH Wafa:** Methodology, identification of ants.

DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

ETHICS AND PERMIT APPROVALS

No ethical approval was required for this study.

DATA AVAILABILITY STATEMENT

Data are contained within the article.

FUNDING STATEMENT

No funding was received to assist with the preparation of this paper.

AI USE STATEMENT

No AI tools were used in the preparation of this paper. All scientific content, data interpretations and conclusions were developed and critically reviewed by the authors.

REFERENCES

- Aissat L. (2023). Diversity and Ant Community Composition in Some Algerian Islands. *Ekológia Bratislava* 42 (1): 17–25. <https://doi.org/10.2478/eko-2023-0003>
- Andersen A.N. (2021). Diversity, biogeography and community ecology of ants: Introduction to the special issue. *Diversity* 13(12): 625. <https://doi.org/10.3390/d13120625>
- Anjos D.V., Tena A., Viana-Junior A.B., Carvalho R.L., Torezan-Silingardi H., Del-Claro K., Perfecto I. (2022). The effects of ants on pest control: a meta-analysis. *Proc R Soc B Biol Sci* 289 (181): 20221316. <https://doi.org/10.1098/rspb.2022.1316>
- Barbault R. (1981). *Ecologie des populations et des peuplements - Des théories aux faits.* MASSON. PARIS, Papier, 200 p. p.
- Barech G., Khaldi M., Cagniant H. (2017). Le genre *Monomorium* (Hymenoptera, Formicidae) au Maghreb (Afrique du nord): cle d'identification, avec la redescription de la fourmi *Monomorium major* Bernard, 1953 et nouvelles citations pour l'Algerie. *Bol SEA* (61): 151–157.
- Borowiec M.L., Moreau C.S., Rabeling C. (2021). Ants: Phylogeny and Classification. In: *Encyclopedia of Social Insects* (Starr C.K., ed), Springer International Publishing, Cham, pp. 52–69. https://doi.org/10.1007/978-3-030-28102-1_155
- Brodie J.F., Williams S., Garner B. (2021). The decline of mammal functional and evolutionary diversity worldwide. *Proc Natl Acad Sci* 118 (3): e1921849118. <https://doi.org/10.1073/pnas.1921849118>

- Cáceres M. D., Legendre P. (2009). Associations between species and groups of sites : Indices and statistical inference. *Ecology* 90(12): 3566-3574. <https://doi.org/10.1890/08-1823.1>
- Cagniant H. (1996a). Les *Aphaenogaster* du Maroc (Hymenoptera: Formicidae): Clé et Catalogue des Espèces. *Ann Société Entomol Fr NS* 32 (1): 67–85. <https://doi.org/10.1080/21686351.1996.12278855>
- Cagniant H. (1996b). Les *Camponotus* du Maroc (Hymenoptera: Formicidae): Clé et Catalogue des Espèces. *Ann Société Entomol Fr NS* 32 (1): 87–100. <https://doi.org/10.1080/21686351.1996.12278857>
- Cagniant H. (1997). Le Genre *Tetramorium* au Maroc (Hymenoptera: Formicidae): Clé et Catalogue des Espèces. *Ann Société Entomol Fr NS* 33 (1): 89–100. <https://doi.org/10.1080/21686351.1997.12279181>
- Cagniant H. (2005). Les *Crematogaster* du Maroc (Hym., Formicidae). Clé de détermination et commentaires. *Orsis Org Sist* 7–12.
- Cagniant H. (2006). Liste actualisée des fourmis du Maroc (Hymenoptera: Formicidae). *Myrmecol Nachrichten* 8: 193–200.
- Cagniant H., Barech G., Khaldi M. (2020). Nouvelle clé des espèces de *Monomorium* Mayr (Hymenoptera: Formicidae) du Maghreb et des Canaries. *Bol SEA* (66): 172–176.
- Calixto E.S., Novaes L.R., Dos Santos D.F.B., Lange D., Moreira X., Del-Claro K. (2021). Climate seasonality drives ant–plant–herbivore interactions via plant phenology in an extrafloral nectary-bearing plant community. *J Ecol* 109 (2): 639–651. <https://doi.org/10.1111/1365-2745.13492>

- Castellarini F., Cuezco F., Luna Toledo E., Buffa L., Orecchia E., Visintín A. (2024). Local and landscape drivers of ground-dwelling ant diversity in agroecosystems of Dry Chaco. *Agric Ecosyst Environ* 367: 108955. <https://doi.org/10.1016/j.agee.2024.108955>
- Castracani C., Mori A. (2006). The role of permanent grasslands on ant community structure: Ants (Hymenoptera: Formicidae) as ecological indicators in the agro-ecosystems of the Taro River Regional Park (Italy). *Myrmecol Nachrichten* 9: 47–54.
- Castracani C., Bulgarini G., Giannetti D., Spotti F.A., Maistrello L., Mori A., Grasso D.A. (2017). Predatory ability of the ant *Crematogaster scutellaris* on the brown marmorated stink bug *Halyomorpha halys*. *J Pest Sci* 90 (4): 1181–1190. <https://doi.org/10.1007/s10340-017-0889-1>
- Cerdá X., Palacios R., Retana J. (2009). Ant community structure in citrus orchards in the Mediterranean Basin: impoverishment as a consequence of habitat homogeneity. *Environ Entomol* 38 (2): 317–324. <https://doi.org/10.1603/022.038.0203>
- Cros S., Cerdá X., Retana J. (1997). Spatial and temporal variations in the activity patterns of Mediterranean ant communities. *Écoscience* 4 (3): 269–278. <https://doi.org/10.1080/11956860.1997.11682405>
- Dauber J., Wolters V. (2004). Edge effects on ant community structure and species richness in an agricultural landscape. *Biodivers Conserv* 13 (5): 901–915. <https://doi.org/10.1023/B:BIOC.0000014460.65462.2b>
- Dudley N., Alexander S. (2017). Agriculture and biodiversity: a review. *Biodiversity* 18 (2–3): 45–49. <https://doi.org/10.1080/14888386.2017.1351892>

- Durot C., Limachi M., Naoki K., Cotter M., Bodenhausen N., Marconi L., Armengot L. (2023). Complexity of cacao production systems affects terrestrial ant assemblages. *Basic Appl Ecol* 73: 80–87. <https://doi.org/10.1016/j.baae.2023.10.006>
- Eisawi K.A., Subedi I.P., Shaheen T., He H. (2022). Impact of land-use changes on ant communities and the retention of ecosystem services in Rashad District, Southern Kordofan, Sudan. *South Afr J Sci* 118 (3–4): 1–9. <https://doi.org/10.17159/sajs.2022/11994>
- Elouafi I. (2024). Why biodiversity matters in agriculture and food systems. *Science* 386 (6718): eads8197. <https://doi.org/10.1126/science.ads8197>
- Folgarait P.J. (1998). Ant biodiversity and its relationship to ecosystem functioning: a review. *Biodivers Conserv* 7 (9): 1221–1244. <https://doi.org/10.1023/A:1008891901953>
- Fonseca A., Zina V., Duarte G., Aguiar F.C., Rodríguez-González P.M., Ferreira M.T., Fernandes M.R. (2021). Riparian Ecological Infrastructures: Potential for biodiversity-related ecosystem services in Mediterranean human-dominated landscapes. *Sustainability* 13 (19): 10508. <https://doi.org/10.3390/su131910508>
- Giannett D., Schifani E., Castracani C., Ghizzoni M., Delaiti M., Penner F., Spotti F.A., Mori A., Ioriatti C., Grasso D.A. (2021). Assessing ant diversity in agroecosystems: the case of Italian vineyards of the Adige Valley. *Redia* 104: 97–109. <https://doi.org/10.19263/REDIA-104.21.11>
- Gliessman S. (2016). Transforming food systems with agroecology. *Agroecol Sustain Food Syst* 40: 187–189. <https://doi.org/10.1080/21683565.2015.1130765>

- Hevia V., Ortega J., Azcárate F.M., López C.A., González J.A. (2019). Exploring the effect of soil management intensity on taxonomic and functional diversity of ants in Mediterranean olive groves. *Agric For Entomol* 21 (1): 109–118. <https://doi.org/10.1111/afe.12313>
- Ikhsan Z., Hidrayani Y., Hamid H., Satria R. (2020). Species diversity and abundance of ants (Hymenoptera: Formicidae) on tidal swamps rice in Indragiri Hilir, Indonesia. *Intl J Adv Res* 8 (12): 658–664. <https://doi.org/10.21474/IJAR01/12194>
- Jandér K.C. (2015). Indirect mutualism: ants protect fig seeds and pollen dispersers from parasites. *Ecol Entomol* 40 (5): 500–510. <https://doi.org/10.1111/een.12215>
- Jing H., Liu Y., Hou J. (2025). Impacts of agricultural intensification on biodiversity: Habitat loss, agrochemical use, water depletion, and soil degradation. *J Environ Manage* 395: 128036. <https://doi.org/10.1016/j.jenvman.2025.128036>
- Kass J.M., Guénard B., Dudley K.L., Jenkins C.N., Azuma F., Fisher B.L., Parr C.L., Gibb H., Longino J.T., Ward P.S., Chao A., Lubertazzi D., Weiser M., Jetz W., Guralnick R., Blatrix R., Lauriers J.D., Donoso D.A., Georgiadis C., Gomez K., Hawkes P.G., Johnson R.A., Lattke J.E., MacGown J.A., Mackay W., Robson S., Sanders N.J., Dunn R.R., Economo E.P. (2022). The global distribution of known and undiscovered ant biodiversity. *Sci Adv* 8 (31): eabp9908. <https://doi.org/10.1126/sciadv.abp9908>
- Keroumi A.E., Naamani K., Soummane H., Dahbi A. (2012). Seasonal dynamics of ant community structure in the Moroccan Argan Forest. *J Insect Sci* 12 (1): 94. <https://doi.org/10.1673/031.012.9401>
- Khadoumi A., Bouzekri A.M., Guerzou A., Daoudi B., Boumakhleb A., Doghbage A., Zemour H., Nafti M., Belhouadjeb A.F. (2025). The effect of phenological stages of *Macrochloa*

- tenacissima L Kunth (syn. *Stipa tenacissima* L.) on myrmecofauna activity in the arid steppes. *International Journal of Environmental Studies* 82 (5–6): 2017–2030. <https://doi.org/10.1080/00207233.2025.2539658>
- Kherbouche D., Bernhard-Reversat F., Moali A., Lavelle P. (2012). The effect of crops and farming practices on earthworm communities in Soummam valley, Algeria. *Eur J Soil Biol* 48: 17–23. <https://doi.org/10.1016/j.ejsobi.2011.09.006>
- Laakel N., Aissat L., Bounab L., Yahiaoui C. (2024). Diversity and Species Composition of Ants in Urban and Suburban Environments in Bejaia City (Algeria). *Sociobiology* 71 (2): e9698–e9698. <https://doi.org/10.13102/sociobiology.v71i2.9698>
- Laoubi K., Yamao M. (2009). A typology of irrigated farms as a tool for sustainable agricultural development in irrigation schemes: The case of the East Mitidja scheme, Algeria. *Int J Soc Econ* 36 (8): 813–831. <https://doi.org/10.1108/03068290910967091>
- Legendre P., Gallagher E. D. (2001). Ecologically meaningful transformations for ordination of species data. *Oecologia*, 129(2): 271–280. <https://doi.org/10.1007/s004420100716>
- Lüdecke D., Ben-Shachar M.S., Patil I., Waggoner P., Makowski D. (2021). performance: An R package for assessment, comparison and testing of statistical models. *J Open Source Softw* 6 (60). <https://doi.org/10.21105/joss.03139>
- Lutinski J.A., Lutinski C.J., Ortiz A., Zembruksi F.S., Ripke M.O., Garcia F.R.M. (2024). Biological Control Using Ants: Current Status, Opportunities, and Limitations. *Agronomy* 14 (7): 1558. <https://doi.org/10.3390/agronomy14071558>
- Magurran, A. E. (2004). *Measuring biological diversity*. United Kingdom: Wiley.

- Martinez Arbizu P. (2020). pairwiseAdonis: Pairwise multilevel comparison using adonis. R package. Version 04. Available URL: <https://github.com/pmartinezarbizu/pairwiseAdonis>.
- Martínez-Núñez C., Rey P.J., Salido T., Manzaneda A.J., Camacho F.M., Isla J. (2021). Ant community potential for pest control in olive groves: Management and landscape effects. *Agric Ecosyst Environ* 305: 107185. <https://doi.org/10.1016/j.agee.2020.107185>
- Oksanen J., Blanchet F.G., Kindt R., Legendre P., Minchin P.R., O'hara R.B., Simpson G.L., Solymos P., Stevens M.H.H., Wagner H. (2013). Package 'vegan'. *Community Ecol Package Version 2* (9): 1–295. Available: <https://CRAN.R-project.org/package=vegan>
- Parker J., Kronauer D.J. (2021). How ants shape biodiversity. *Curr Biol* 31 (19): R1208–R1214. <https://doi.org/10.1016/j.cub.2021.08.015>
- Parr C.L., Eggleton P., Davies A.B., Evans T.A., Holdsworth S. (2016). Suppression of savanna ants alters invertebrate composition and influences key ecosystem processes. *Ecology* 97 (6): 1611–1617. <https://doi.org/10.1890/15-1713.1>
- Perfecto I., Armbrrecht I., Philpott S.M., Soto-Pinto L., Dietsch T.V. (2007). Shaded coffee and the stability of rainforest margins in northern Latin America. In: *Stability of Tropical Rainforest Margins, Environmental Science and Engineering* (Tscharrntke T., Leuschner C., Zeller M., Guhardja E., Bidin A., eds), Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 225–261. https://doi.org/10.1007/978-3-540-30290-2_12
- Pilling D., Bélanger J., Hoffmann I. (2020). Declining biodiversity for food and agriculture needs urgent global action. *Nat Food* 1 (3): 144–147. <https://doi.org/10.1038/s43016-020-0040-y>

- Platner C., Piñol J., Sanders D., Espadaler X. (2012). Trophic diversity in a Mediterranean food web—Stable isotope analysis of an ant community of an organic citrus grove. *Basic Appl Ecol* 13 (7): 587–596. <https://doi.org/10.1016/j.baae.2012.09.006>
- Queiroz A.C.M., Marques T.G., Ribas C.R., Cornelissen T.G., Nogueira A., Schmidt F.A., Feitosa R.M., Sobrinho T.G., Quinet Y., Baccaro F.B., Ulysséa M.A., Vargas A.B., Morini M.S.C., Souza J.L.P., Paolucci L.N., Dáttilo W., Del-Claro K., Lange D., Santos J.C., Silva R.R., Campos R.B.F., Albuquerque E.Z., Izzo T., Rabello A.M., Solar R.R.C., Soares S.A., Carvalho K.S., Moraes A.B., Torezan-Silingardi H.M., Nahas L., Dos Santos I.A., Costa-Milanez C.B., Esteves F., Frizzo T., Harada A.Y., DaRocha W., Diehl-Fleig E. (2023). Ant diversity decreases during the dry season: A meta-analysis of the effects of seasonality on ant richness and abundance. *Biotropica* 55 (1): 29–39. <https://doi.org/10.1111/btp.13158>
- Sampaio R.C., da Silva Laviski B.F., de Souza Coelho R.C., de Queiroz J.M. (2023). Effects of vegetation structure on ant diversity in different seasonal periods in impacted fragments of Atlantic Forest. *Sociobiology* 70 (2): e7949–e7949. <https://doi.org/10.13102/sociobiology.v70i2.7949>
- Sanchez J.A., Carrasco-Ortiz A., López-Gallego E., Ramírez-Soria M.J., La Spina M. (2021). Ants reduce fruit damage caused by psyllids in Mediterranean pear orchards. *Pest Manag Sci* 77 (4): 1886–1892. <https://doi.org/10.1002/ps.6213>
- Sankovitz M., Rivera M.J., Manjarres T., Mathis K.A. (2024). The role of ant-mediated biological interactions in agroecosystems. *Ann Entomol Soc Am* 117 (2): 79–91. <https://doi.org/10.1093/aesa/saae002>

- Santos P.Z.F., Crouzeilles R., Sansevero J.B.B. (2019). Can agroforestry systems enhance biodiversity and ecosystem service provision in agricultural landscapes? A meta-analysis for the Brazilian Atlantic Forest. *For Ecol Manag* 433: 140–145. <https://doi.org/10.1016/j.foreco.2018.10.064>
- Schifani E., Alicata A. (2023). Plesiobiotic Associations Between Ants: A Common Yet Underreported Phenomenon in the Mediterranean Region? *Sociobiology* 70 (1): e8547–e8547. <https://doi.org/10.13102/sociobiology.v70i1.8547>
- Schifani E., Giannetti D., Grasso D.A. (2023). Predatory abilities of two Mediterranean ants on the eggs and larvae of the codling moth *Cydia pomonella*. *Insects* 14 (2): 97. <https://doi.org/10.3390/insects14020097>
- Schifani E., Alicata A., Menchetti M., Borowiec L., Fisher B.L., Karaman C., Kiran K., Oueslati W., Salata S., Blatrix R. (2022). Revisiting the morphological species groups of West-Palearctic *Aphaenogaster* ants (Hymenoptera: Formicidae) under a phylogenetic perspective: toward an evolutionary classification. *Arthropod Syst Phylogeny* 80: 627–648. <https://doi.org/10.3897/asp.80.e84428>
- Seifert B. (1992). A taxonomic revision of the Palaearctic members of the ant subgenus *Lasius* s. str. (Hymenoptera, Formicidae). *Abh Berichte Naturkundemuseums Görlitz* 66: 1–67.
- Seifert B. (2016a). Inconvenient hyperdiversity—the traditional concept of “*Pheidole pallidula*” includes four cryptic species (Hymenoptera: Formicidae). *Soil Org* 88 (1): 1–17. <https://doi.org/10.5281/zenodo.270253>
- Seifert B. (2016b). Analyzing large-scale and intranidal phenotype distributions in eusocial Hymenoptera - A taxonomic tool to distinguish intraspecific dimorphism from

- heterospecificity. Myrmecol News 23: 41–59.
https://doi.org/10.25849/myrmecol.news_023:041
- Seifert B. (2017). The ecology of Central European non-arboreal ants—37 years of a broad-spectrum analysis under permanent taxonomic control: + Electronic supplement is linked to the online version of the paper. Soil Org 89 (1): 1–69.
- Seifert B. (2020). The gene and gene expression (GAGE) species concept: an universal approach for all eukaryotic organisms. Syst Biol 69 (5): 1033–1038.
<https://doi.org/10.1093/sysbio/syaa032>
- Seifert B. (2022). The ant genus Cardiocondyla (Hymenoptera: Formicidae): the species groups with Oriental and Australasian origin. Diversity 15 (1): 25.
<https://doi.org/10.3390/d15010025>
- Siddiqui J.A., Bamisile B.S., Khan M.M., Islam W., Hafeez M., Bodlah I., Xu Y. (2021). Impact of invasive ant species on native fauna across similar habitats under global environmental changes. Environ Sci Pollut Res 28: 54362–54382. <https://doi.org/10.1007/s11356-021-15961-5>
- Smargiassi S., Masoni A., Frizzi F., Balzani P., Desiato E., Benelli G., Canale A., Santini G. (2023). Keep your eggs away: ant presence reduces *Ceratitis capitata* oviposition behaviour through trait-mediated indirect interactions. Insects 14 (6): 532.
<https://doi.org/10.3390/insects14060532>
- Stoklosa J., Blakey R.V., Hui F.K. (2022). An overview of modern applications of negative binomial modelling in ecology and biodiversity. Diversity 14 (5): 320.
<https://doi.org/10.3390/d14050320>

- Tozetto L., Forrister D.L., Duval M., Hays T., Garwood N.C., Castro R.V., Lattke J.E., Sendoya S., Longino J.T. (2023). Army ant males lose seasonality at a site on the equator. *Biotropica* 55 (2): 382–395. <https://doi.org/10.1111/btp.13192>
- Udawatta R.P., Rankoth L.M., Jose S. (2019). Agroforestry and biodiversity. *Sustainability* 11 (10): 2879. <https://doi.org/10.3390/su11102879>
- Van Kolschoten L., Asantewaa M.A., Dück L., Segar S.T., Jander K.C. (2024). Specialist fig-consuming lepidopterans can inflict costs to plant reproductive success that are mitigated by ant bodyguards. *Acta Oecologica* 124: 104016. <https://doi.org/10.1016/j.actao.2024.104016>
- Yang M., Chen T., Liu Y., Huang L. (2024). Visualizing set relationships: EVenn’s comprehensive approach to Venn diagrams. *iMeta* 3 (3): e184. <https://doi.org/10.1002/imt2.184>
- Zina V., Conde S., Branco M., Franco J.C. (2024). Do dominant native ants outcompete the invasive Argentine ant in Mediterranean citrus ecosystems? A laboratory test. *Insects* 15 (5): 333. <https://doi.org/10.3390/insects15050333>
- Zina V., Fonseca A., Duarte G., Conde S., Fernandes M.R., Ferreira M.T., Franco J.C. (2022). Ant diversity is enhanced by ecological infrastructures in agroecosystems: A case study in irrigated mediterranean farmland. *Agronomy* 12 (11): 2690. <https://doi.org/10.3390/agronomy12112690>

Table 1. The agricultural management practices suited to different sectors

Sector	Orchard	Cultivation	Irrigation	Tillage/Plowing Depth	Mechanical Weeding	Pesticide Application
KSR	O 1	Citrus	Gravity	1 time/year 25 cm	Disc harrow	Cypermethrin 250 g/l Chlorcyrine 220 EC Copper oxychloride 678.6 g/l
	O 2	Pear	Gravity	1 time/year 25 cm	Disc harrow	Cypermethrin 250 g/l Chlorcyrine 220 EC Copper oxychloride 678.6 g/
ITAF	O 1	Fig	/	1 time/year 25 cm	Disc harrow	/
	O 2	Olive	Sprinkler	1 time/year 25 cm	Disc harrow	/

Table 2. Ant species Richness (S) and abundance of each crop type of Soummam Valley's agroecosystems (CTS = Citrus, PR = Pear, FG = Fig, OLV = Olive)

Sub-famillies	Species	CTS	PR	FG	OLV
Dolichoderinae	<i>Tapinoma magnum</i> (Mayr, 1861)	10	-	28	5
	<i>Tapinoma simrothi</i> (Krausse, 1911)	104	228	326	37
Formicinae	<i>Camponotus foreli</i> (Emery, 1881)	-	1	-	-
	<i>Camponotus lateralis</i> (Santschi, 1929)	-	-	-	1
	<i>Camponotus piceus</i> (Leach, 1825)	-	2	-	-
	<i>Camponotus thoracicus</i> (Fabricius, 1804)	-	-	3	-
	<i>Cataglyphis bicolor</i> (Fabricius, 1793)	13	41	373	190
	<i>Lepisiota frauenfeldi atlantis</i> (Santschi, 1917)	-	1	182	30
	<i>Plagiolepis schmitzii</i> (Forel, 1895)	33	25	19	3
Myrmicinae	<i>Aphaenogaster mauritanica</i> (Dalla Torre, 1893)	9	-	1	-
	<i>Aphaenogaster testaceopilosa</i> (Lucas, 1849)	57	75	-	1
	<i>Cardiocondyla batesii</i> (Forel, 1894)	-	-	4	5
	<i>Crematogaster aubertii</i> (Emery, 1869)	-	-	65	1
	<i>Crematogaster scutellaris</i> (Olivier, 1792)	1	-	10	5
	<i>Messor barbarus</i> (Linnaeus, 1767)	813	1612	47	-
	<i>Monomorium andrie</i> (Saunders, 1890)	7	1	93	13
	<i>Monomorium salomonis</i> (Linnaeus, 1758)	-	-	117	468
	<i>Pheidole cicatricosa</i> (Stitz, 1917)	109	14	42	12
	<i>Solenopsis sp.</i> (Westwood, 1840)	5	2	2	3

	<i>Strumigenys membranifera</i> (Emery, 1869)	2	-	-	-
	<i>Temnothorax recedens</i> (Nylander, 1856)	0	0	26	2
	<i>Tetramorium forte</i> (Forel, 1904)	39	33	13	8
	<i>Tetramorium semilaeve</i> (André, 1883)	1	-	1	14
Ponerinae	<i>Hypoponera eduardi</i> (Forel, 1894)	1	-	-	-
Total abundance		1204	2035	1352	798
Richness (S)		15	12	18	17

758

759

760

761

762

763

764

765

766

767

768

769

Table 3. Diversity parameters of ants following crops, in Soummam Valley's agroecosystems

Crop type	Citrus	Pear	Fig	Olive
Richness_S	15	12	18	17
Abundance	1204	2035	1352	798
Shannon_H	1.25	0.81	2.08	1.34
Evenness	0.46	0.32	0.72	0.47
Simpson (1-D)	0.52	0.36	0.83	0.59

Table 4. Generalized Linear Model (GLM with Quasi-Poisson error structure) evaluating the effects of crop type and season on ant species richness. The model is additive (Crop + Season; $n = 12$ sampling units; 6 residual degrees of freedom), with a log link and an estimated dispersion parameter ($\phi = 0.94$). Reference levels: Crop = Citrus; Season = Autumn. Overall test for the effect of season: $F(2, 6) = 10.32$, $p = 0.011$.

Parameter / Predictor	Estimate	Std. Error	t-value	<i>p</i> -value	Exp (Estimate)	Significance
Intercept (Citrus + Autumn)	2.64259	0.19616	13.472	0.000010	14.05	*** ($p < 0.001$)
Crop [Fig]	-0.02985	0.23631	-0.126	0.903598	0.97	Non-Significant
Crop [Olive]	-0.09237	0.24015	-0.385	0.713760	0.91	Non-Significant
Crop [Pear]	-0.39087	0.26108	-1.497	0.185010	0.68	Non-Significant
Season [Summer]	0.03922	0.19154	0.205	0.844524	1.04	Non-Significant
Season [Winter]	-0.96758	0.26062	-3.713	0.009938	0.38	** ($p < 0.01$)

Table 5. PERMANOVA on Hellinger-transformed abundance data (additive model: Crop + Season; 999 permutations). Df= degrees of freedom (Crop: 4 levels – 1 = 3; Season: 3 levels – 1 = 2; Residual: 11 – 5 = 6; Total: 11). R^2 = proportion of total variance explained. ¹ Total sum of squares. Because the design is balanced, the terms are orthogonal and the R^2 of Crop (0.300) and Season (0.272) add up, within rounding error, to the R^2 of the full model ($0.571 = 1 - 0.429$). Significance codes: ns = $p > 0.05$.

Source	Df	SumOfSqs	R^2	F	<i>p-value</i>	Sig.
Crop type	3	0.630	0.300	1.398	0.294	ns
Season	2	0.572	0.272	1.908	0.128	ns
Full model (Crop + Season)	5	1.202	0.571	1.600	0.175	ns
Residual	6	0.901	0.429	—	—	
Total	11	2.103 ¹	1.000	—	—	

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns $p > 0.1$ (not significant).

Table 6. Indicator Species Analysis (IndVal.g, indicpecies package; 999 permutations). Association function: IndVal.g. Stat = 1.0 indicates perfect fidelity and specificity to the crop group. Significance codes: * $p < 0.05$; ns = not significant; — = not applicable. p-values are not adjusted for multiple testing across species.

Species	Associated crop group	IndVal Stat	<i>p-value</i>	Sig.	Ecological interpretation
<i>Messor barbarus</i> (Linnaeus, 1767)	Citrus + Fig + Pear	1.000	0.017	*	Dominant harvester ant; functionally excluded from Olive groves, likely due to open-soil management and reduced seed availability.
All other species (n = 23)	—	< threshold	> 0.05	ns	No significant association with any single crop type; typical Mediterranean generalist fauna shared across all orchards.

Supplementary Table S1. Additive generalized linear models (Crop + Season; $n = 12$ sampling units = 4 crops $\times$ 3 seasons; 6 residual degrees of freedom) for total abundance, Shannon diversity, Simpson diversity and evenness. Reference levels: Crop = Citrus; Season = Winter (Wald tests; 6 residual df). Estimates are on the link scale (log for abundance; identity for the other variables). Test statistic: z (negative binomial) or t (Gaussian). Species richness (quasi-Poisson, log link) is reported in Table 4 of the main text. ns = not significant.

Response variable (distribution, link)	Predictor	Estimate	Std. error	Test statistic	<i>p</i> -value
Total abundance (negative binomial, log link)	Intercept (Citrus, Winter)	3.910	0.380	10.277	< 0.001
	Crop [Fig]	−0.076	0.435	−0.175	0.861
	Crop [Olive]	−0.558	0.437	−1.276	0.202
	Crop [Pear]	1.063	0.433	2.457	0.014
	Season [Summer]	2.930	0.378	7.747	< 0.001
	Season [Autumn]	1.417	0.379	3.734	< 0.001
Shannon diversity, H' (Gaussian, identity link)	Intercept (Citrus, Winter)	1.162	0.252	4.606	0.004
	Crop [Fig]	0.223	0.291	0.764	0.474
	Crop [Olive]	−0.198	0.291	−0.679	0.522
	Crop [Pear]	−0.715	0.291	−2.454	0.050

Response variable (distribution, link)	Predictor	Estimate	Std. error	Test statistic	<i>p</i>-value
	Season [Summer]	0.123	0.252	0.486	0.644
	Season [Autumn]	0.727	0.252	2.881	0.028
Simpson diversity, 1 – D (Gaussian, identity link)	Intercept (Citrus, Winter)	0.565	0.101	5.599	0.001
	Crop [Fig]	0.110	0.116	0.941	0.383
	Crop [Olive]	0.005	0.116	0.042	0.968
	Crop [Pear]	–0.262	0.116	–2.254	0.065
	Season [Summer]	–0.051	0.101	–0.505	0.631
	Season [Autumn]	0.178	0.101	1.762	0.129
Pielou’s evenness, E (Gaussian, identity link)	Intercept (Citrus, Winter)	0.705	0.087	8.090	< 0.001
	Crop [Fig]	0.168	0.101	1.672	0.146
	Crop [Olive]	0.064	0.101	0.633	0.550
	Crop [Pear]	–0.209	0.101	–2.080	0.083
	Season [Summer]	–0.286	0.087	–3.281	0.017
	Season [Autumn]	–0.037	0.087	–0.421	0.688

Supplementary Table S2. Data of the 12 sampling units (pooled pitfall-trap line per orchard and season; winter = December–February, summer = June–August, autumn = September–November). S = species richness, N = total abundance, H' = Shannon index (natural logarithm), $1 - D$ = Simpson diversity, E = Pielou's evenness ($H'/\ln S$). Values are rounded to three decimals; statistics recomputed from these rounded values (e.g., the correlations in Fig. 3) may differ slightly in the third decimal.

Crop	Season	S	N	H'	$1 - D$	E
Citrus	Autumn	13	111	1.961	0.807	0.765
Citrus	Summer	12	1024	1.002	0.414	0.403
Citrus	Winter	9	69	1.373	0.599	0.625
Fig	Autumn	15	262	2.317	0.885	0.856
Fig	Summer	15	1074	1.856	0.787	0.685
Fig	Winter	3	16	0.831	0.477	0.757
Olive	Autumn	12	178	1.503	0.645	0.605
Olive	Summer	16	612	1.200	0.565	0.433
Olive	Winter	3	8	1.040	0.625	0.946
Pear	Autumn	10	350	1.085	0.483	0.471
Pear	Summer	9	1409	0.392	0.140	0.178
Pear	Winter	4	276	0.714	0.410	0.515

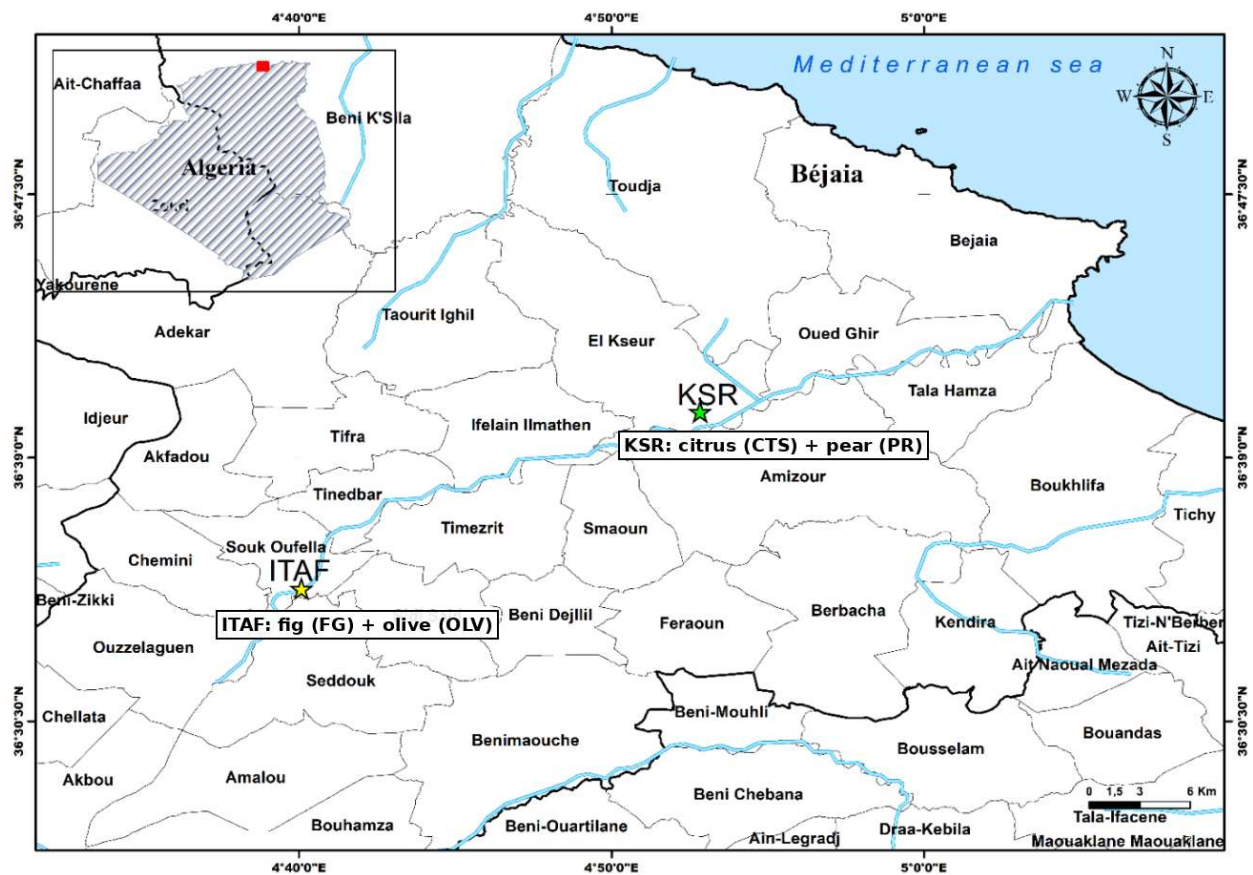


Figure 1. Geographic location of study areas and sampling sites (KSR = El Kseur, ITAF = National Institute of Fruit Trees and Vine) (QGIS 3.34.12). Each crop was sampled in a single orchard: fig (FG) and olive (OLV) at ITAF; citrus (CTS) and pear (PR) at KSR

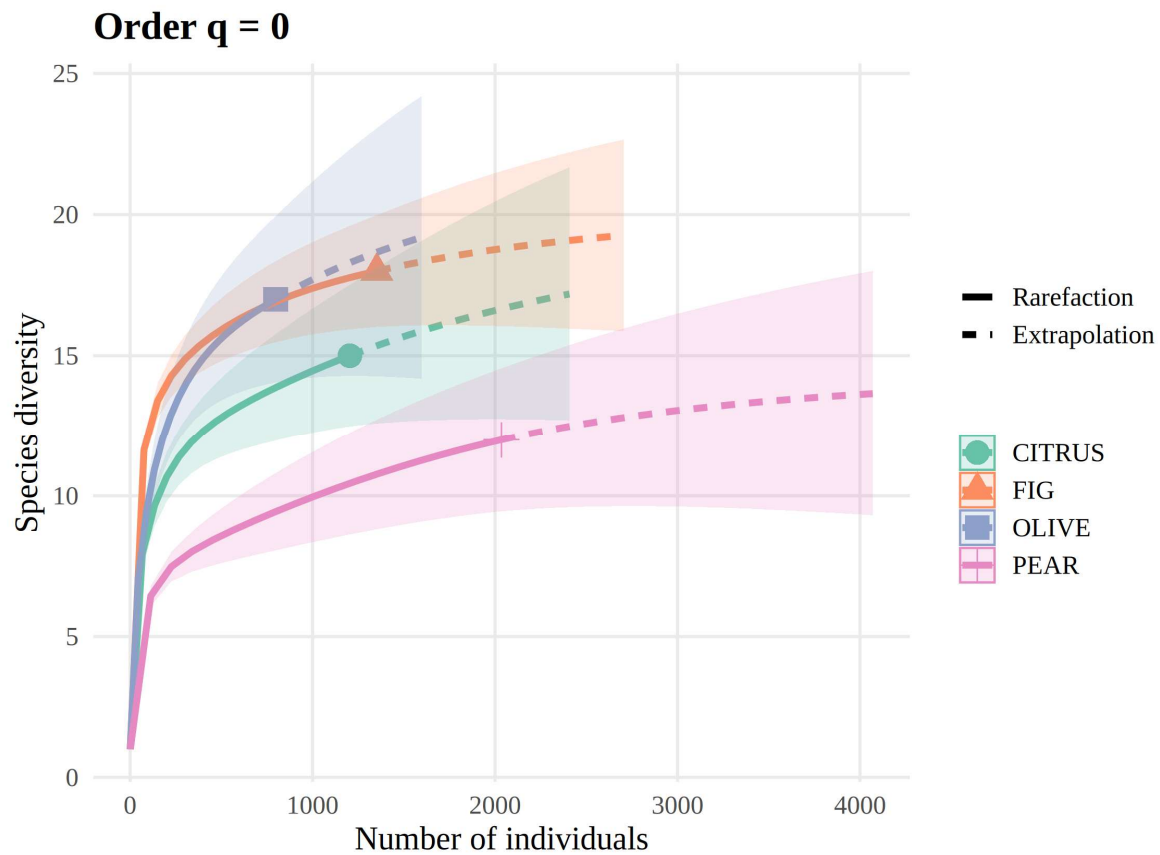


Figure 2. Rarefaction and extrapolation curves of ant species diversity for the four crop types (Citrus, Pear, Fig and Olive) in Soummam Valley's agroecosystems.

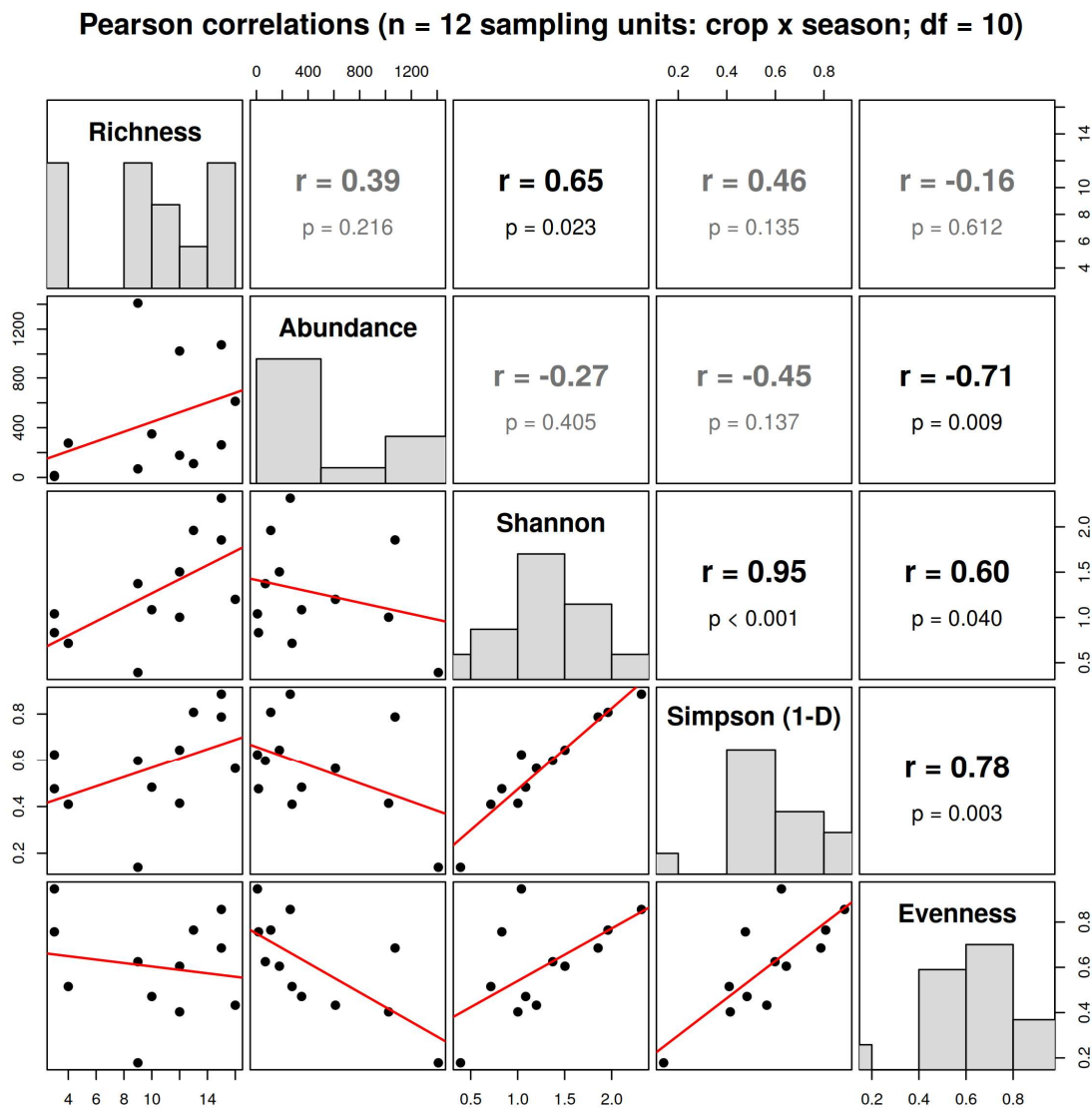


Figure 3. Pearson correlation matrix among species richness, total abundance, Shannon (H'), Simpson ($1 - D$) and evenness (E), computed across the 12 sampling units (crop $\times$ season; $n = 12$, $df = 10$). Upper panels: Pearson's r and exact two-sided p -value (not corrected for multiple testing); lower panels: scatterplots with linear fit; diagonal: histograms.

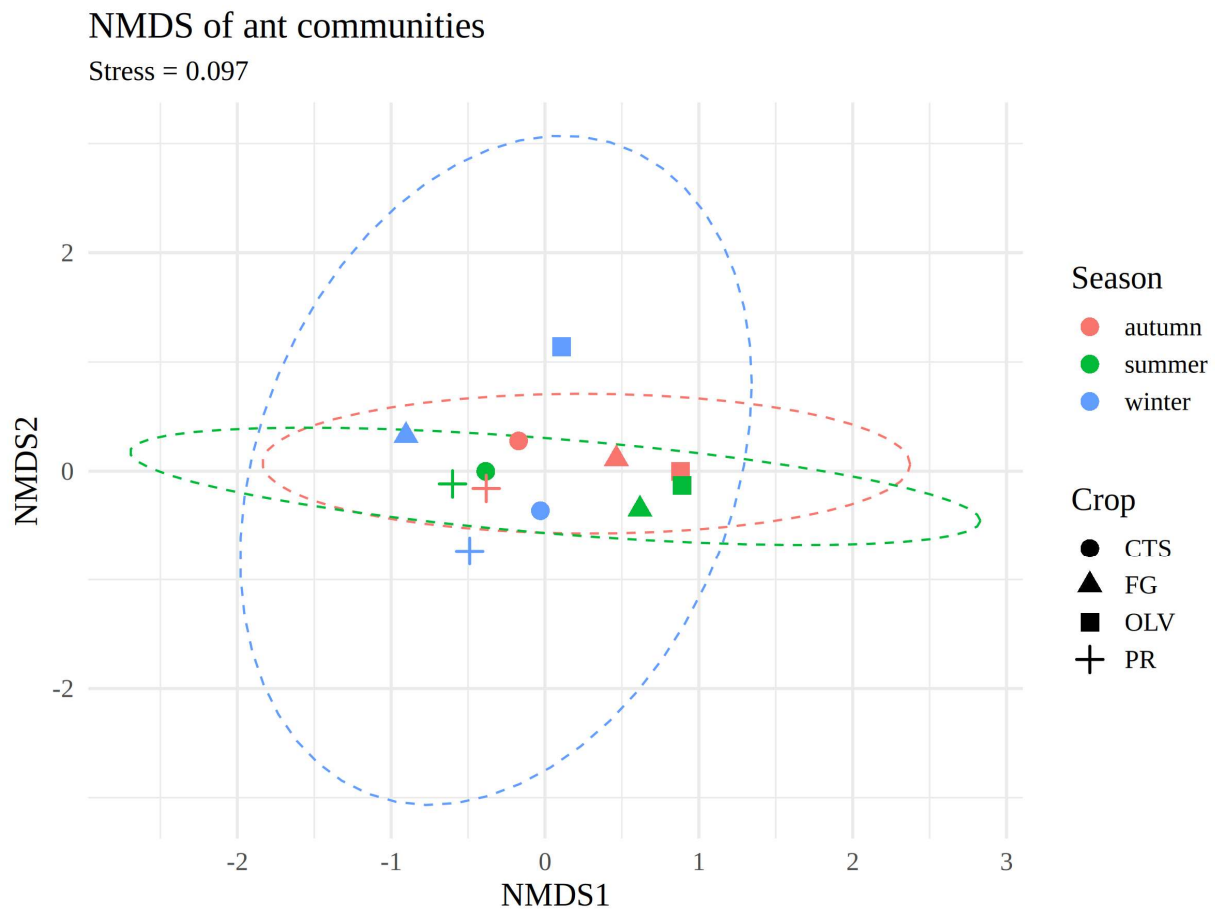
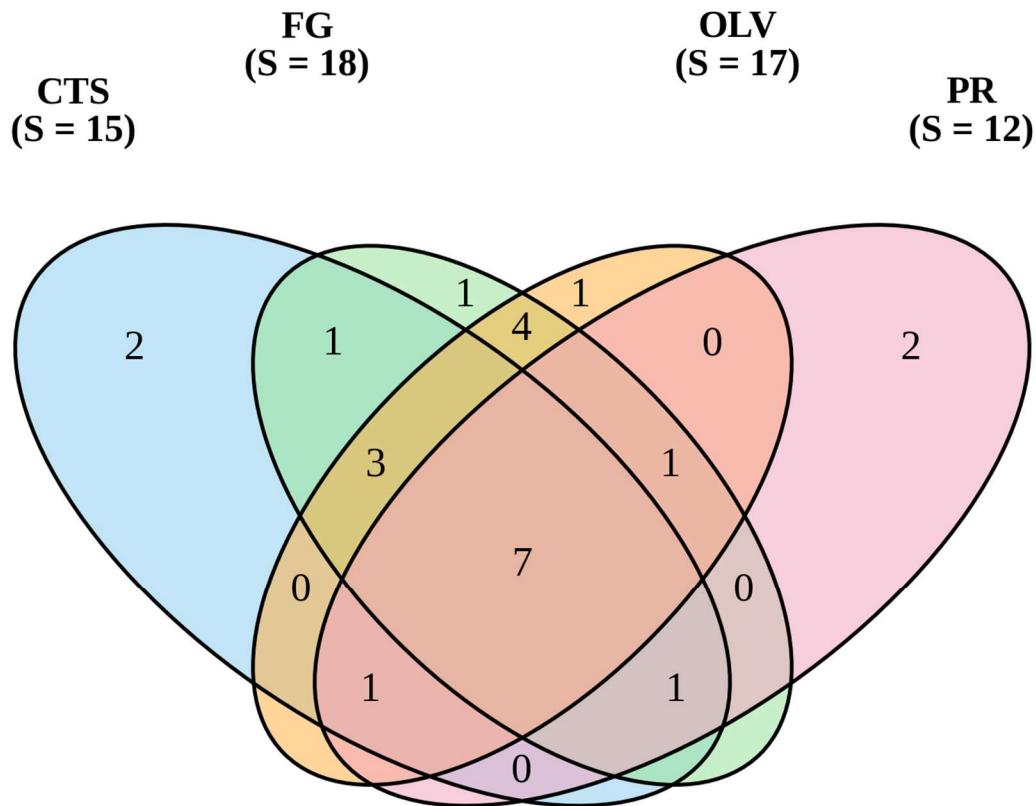


Figure 4. Non-metric multidimensional scaling of ant communities of the four crop types in Winter, Summer, and Autumn. (CTS = Citrus, FG = Fig, OLV = Olive, PR = Pear). Ordination based on Bray–Curtis dissimilarity of Hellinger-transformed abundances (stress = 0.097). Ellipses are 95% confidence ellipses computed around the four sampling units of each season and are descriptive only.



848

849 **Figure 5.** Venn diagram showing the number of ant species unique to, or shared among, the four
 850 orchards (numbers = species counts; S = species richness of each orchard; total = 24 species). (CTS
 851 = Citrus, FG = Fig, OLV = Olive, PR = Pear).

Figure 1. Geographic location of study areas and sampling sites (KSR = El Kseur, ITAF = National Institute of Fruit Trees and Vine) (QGIS 3.34.12). Each crop was sampled in a single orchard: fig (FG) and olive (OLV) at ITAF; citrus (CTS) and pear (PR) at KSR.

Figure 2. Rarefaction and extrapolation curves of ant species diversity for the four crop types (Citrus, Pear, Fig and Olive) in Soummam Valley's agroecosystems.

Figure 3. Pearson correlation matrix among species richness, total abundance, Shannon (H'), Simpson ($1 - D$) and evenness (E), computed across the 12 sampling units (crop $\times$ season; $n = 12$, $df = 10$). Upper panels: Pearson's r and exact two-sided p -value (not corrected for multiple testing); lower panels: scatterplots with linear fit; diagonal: histograms.

Figure 4. Non-metric multidimensional scaling of ant communities of the four crop types in Winter, Summer, and Autumn. (CTS = Citrus, FG = Fig, OLV = Olive, PR = Pear). Ordination based on Bray–Curtis dissimilarity of Hellinger-transformed abundances (stress = 0.097). Ellipses are 95% confidence ellipses computed around the four sampling units of each season and are descriptive only.

Figure 5. Venn diagram showing the number of ant species unique to, or shared among, the four orchards (numbers = species counts; S = species richness of each orchard; total = 24 species). (CTS = Citrus, FG = Fig, OLV = Olive, PR = Pear).