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Soil Arthropod Diversity and Their Functional Roles in Soil Health and Agroecosystem Sustainability in Telangana.

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ABSTRACT

Soil arthropods are ecologically diverse invertebrates inhabiting soil at one or more life stages, including isopods, mites, ticks, spiders, scorpions, centipedes, millipedes, ants, beetles, springtails, and related taxa. They play crucial roles in nutrient cycling, organic matter decomposition, soil aeration, and fertility, particularly in arid and semi-arid regions such as erstwhile Nizamabad District, Telangana. This study assessed the diversity and functional roles of soil arthropods under tree-based systems compared with adjacent open agricultural fields. Sampling was conducted using quadrat methods, Berlese (Tullgren) funnels, and pitfall traps across sites with native tree cover (Prosopis cineraria, Azadirachta indica, Tecomella undulata) and open fields. Results revealed significantly higher arthropod diversity and abundance under tree cover, strongly correlated with improved soil structure, organic matter accumulation, and nutrient availability (N, P, K). Tree cover provided stable microhabitats by moderating soil temperature, conserving moisture, and contributing litter, supporting detritivores and predator activity. Dominant arthropod groups included Insecta (Diptera, Hymenoptera, Coleoptera, Hemiptera), Arachnida (Mesostigmata, Oribatida, Araneae), and Collembola. Diversity indices indicated greater species richness under Prosopis cineraria (Shannon H′ = 2.23; Margalef DMg = 1.67) and reduced diversity in open fields (H′ = 2.02; DMg = 1.52).Overall, the study highlights soil arthropods as key indicators and facilitators of soil health, emphasizing the ecological significance of conserving tree cover within agricultural landscapes to sustain biodiversity, nutrient cycling, and agro ecosystem sustainability in semi-arid regions.

Keywords: Soil arthropods; tree cover; nutrient cycling; biodiversity; decomposition; agroecosystem sustainability.

INTRODUCTION

Soil, as a highly diverse and dynamic system, plays a critical role in determining ecosystem services and agricultural productivity. It consists of a complex mixture of organic and mineral matter at the Earth’s surface, providing the physical matrix and biochemical environment necessary for plant growth. Microorganisms are central to nutrient cycling and their availability to crops, with clear distinctions observed in the biodiversity of the rhizosphere versus bulk soil (Beed et al., 2017). Soil fertility, defined as the capacity of soil to supply essential nutrients and water along with physical support for healthy root development, is greatly influenced by biological activity (Culliney, 2013). The ability of soil to meet plant requirements for vital nutrients necessary for growth and reproduction remains a cornerstone of agricultural sustainability (Sm et al., 2024).

Arthropods, the largest animal phylum with more than 1.5 million described species, constitute nearly 80% of all known organisms (Zhang, 2011). Within this group, Hexapoda is the dominant subphylum, comprising 84% of all Arthropoda and nearly 69% of all documented species in the Animalia kingdom (Chandra et al., 2021). Soil arthropods are fundamental to soil health, quality, and ecosystem functioning. They contribute to the breakdown and decomposition of organic matter, soil structure formation, and nutrient cycling (Menta & Remelli, 2020). By providing such critical ecosystem services, soil arthropods significantly enhance the ecological resilience and welfare of soil ecosystems (Abajue et al., 2024).

Trees also provide vital ecological benefits, including improved nutrient cycling and enhancement of soil physical and chemical properties. Their inclusion in agricultural systems fosters soil fertility and supports biodiversity. Particularly in arid and semi-arid environments, tree species such as Prosopis cineraria, Acacia senegal, and Tecomella undulata have been identified as ideal for sustaining productivity under harsh conditions. These species tolerate drought, poor soil fertility, moisture deficits, and high soil temperatures (Kumar et al., 2017). Among them, Tecomella undulata (Rohida or desert teak) is a key timber species in India's dry regions. Foliar development and flowering begin in September and extend until February or March, during which time numerous foliar pests and insect visitors are recorded (Verma & Vir, 1995). Compared to herbaceous systems, tree-based agriculture is often more effective at nutrient cycling due to the deeper and more extensive rooting systems of trees (Sundaramoorthy et al., 2009).

Soil represents the very foundation of both natural and agricultural ecosystems, supporting the majority of terrestrial life forms. The thin layer of soil on the Earth's surface often determines the difference between species survival and extinction (Doran & Zeiss, 2000). Identifying reliable soil health indicators is essential for sustainable land management. Such indicators must be sensitive to management changes, correlate strongly with beneficial soil functions, remain easily understood and applicable by land managers, and be both affordable and simple to measure (Parisi et al., 2005). Within the soil mesofauna, Acari and Collembola are dominant groups. Collembola, which feed on microbial films, fungal hyphae, and plant debris, can influence soil structure and functioning. Within Acari, the Mesostigmata and Oribatida are ecologically significant suborders, with oribatid mites being particularly diverse and abundant in undisturbed soils (George et al., 2017).

Soil microarthropods also enhance microbial activity and chemical degradation by fragmenting plant litter and coarse woody debris, thereby accelerating decomposition and nutrient cycling (Tripathi et al., 2009). Their interactions are strongly influenced by soil conditions, and their activities are closely linked to microbial processes critical for agriculture (Singh et al., 2017). For example, isopods contribute to decomposition by dispersing fungal spores and bacterial propagules through fecal pellets, thereby supporting microbiota involved in litter breakdown (Zimmer, 2002). Such interactions sustain the multitude of active soil organisms responsible for carbon turnover, nutrient cycling, residue decomposition, pest suppression, and disease regulation. Soils harbor remarkably complex food webs, containing billions of bacterial cells, hundreds of meters of fungal hyphae, and numerous invertebrate groups within a single gram of soil (Sofo et al., 2020).

Soil invertebrates are typically classified into four groups based on size: (1) microfauna (20–200 µm; protozoa, nematodes, crustaceans, rotifers), (2) mesofauna (200 µm–2 mm; mites, springtails, insect larvae, pseudoscorpions), (3) macrofauna (2–20 mm; insects, earthworms, isopods), and (4) megafauna (>20 mm; vertebrates such as rodents and reptiles) (Raza et al., 2019). Despite their ecological significance, below-ground multitrophic interactions are often overlooked, with most studies historically focusing on above-ground dynamics (Altieri et al., 2012). However, soil biodiversity and faunal activity are under threat from anthropogenic pressures. Intensive agricultural practices, including heavy tillage and agrochemical inputs, reduce soil faunal diversity and microbial activity, often overriding natural biological regulation of soil processes (Devi et al., 2019).

The present study investigates the diversity and functional roles of soil arthropods in tree-based systems compared to adjacent open agricultural fields in erstwhile Nizamabad District, Telangana. The research emphasizes the relationship between soil arthropod diversity and soil health indicators, aiming to generate region-specific insights into the ecological value of integrating native trees within agricultural landscapes. By highlighting the role of tree cover in supporting soil biodiversity, nutrient cycling, and ecological resilience, this study provides crucial evidence for developing sustainable agro ecosystem management strategies in semi-arid regions

MATERIALS AND METHODS

Study Area

The study was carried out in the erstwhile Nizamabad District, Telangana, located in a semi-arid region characterized by hot summers, low rainfall, and sparse vegetation. The selected sites included areas under native tree species such as Prosopis cineraria (L.) Azadirachta indica and Tecomella undulata, along with adjacent open agricultural fields without tree cover. These contrasting habitats allowed for comparative analysis of soil arthropod diversity and their functional roles in relation to soil health and agro ecosystem sustainability.

Fauna Collection and Extraction

Quadrat Method

The study sites were divided into smaller quadrats for systematic sampling. Corners of each quadrat were marked using stakes and flags. Soil samples were collected from the 5–15 cm depth using a shovel between July 2024 and June 2025. Each sample was placed in labeled ziplock bags, containing information such as site name, sampler name, date, and time of collection.

Pitfall Traps

Ground-dwelling arthropods were sampled using pitfall traps. Small plastic containers were buried with their rims level to the soil surface and filled with preservative liquid (70% ethanol or propylene glycol). Traps were left in the field for 24–72 hours to capture active arthropods.

Tullgren (Berlese) Funnels
Smaller soil arthropods were extracted using Tullgren funnels. Soil samples were placed in the funnels for 24 hours, and the descending arthropods were collected into vials containing 70% ethanol. Specimens were sorted under a stereoscopic microscope, separated into taxonomic groups, and preserved in alcohol-filled jars. Smaller specimens were further processed for slide preparation by dehydration through graded alcohols, staining with eosin, and mounting in DPX.

Soil Analysis
Physical Properties
Soil texture was analyzed using the Mason jar method. Soil samples were sieved to remove stones, roots, and organic debris, and aggregates were broken down before testing. Approximately one-fourth of the jar was filled with soil, water, and a small amount of Borax to facilitate clay particle settling. After shaking for 3 to 4 minutes, the samples were left to settle, and layer thicknesses were measured. Percentages of sand, silt, and clay were calculated, and soil texture was determined using the USDA soil texture triangle.

Chemical Properties
Soil chemical characteristics were determined for each sampling site. Soil pH: measured using a digital pH meter. Organic matter content: determined by standard methods.
Phosphorus (P): analyzed using Olsen, Bray, and Mehlich-3 extraction methods, depending on soil type. Potassium (K): determined using Flame Photometry. Nitrogen (N): estimated through standard Kjeldahl method.

Data Analysis
Soil arthropod diversity and abundance were analyzed using ecological diversity indices:

Simpson's Diversity Index (1–D): $D = 1 - \sum n(n-1)/N(N-1)$
Where n = number of individuals of a species, and N = total number of individuals.

Shannon-Wiener Index (H′): $H' = -\sum P_i \log_2 P_i$
Where P_i = proportion of individuals of species i in the total population.

Pielou's Evenness Index (J): Calculated to assess evenness of species distribution.

Margalef's Species Richness Index (DMg): $DMg = (S-1)/\ln N$
Where S = total number of species, N = total number of individuals.
These indices were applied to evaluate the richness, abundance, and diversity of soil arthropods under tree-based and open field systems, and their relationship with soil properties.

Table 1. Physico-chemical properties of experimental soil (5-15 cm)

Physico-chemical properties	Prosopis cineraria	Azadirachta indica	Tecomella undulata	Open agricultural field
pH	8.2±0.12	8.1±0.10	8.1±0.11	8.2±0.11
EC(ds/m)	0.15±0.009	0.16±0.009	0.14±0.006	0.14±0.006
Organic Carbon (%)	0.29±0.01	0.38±0.01	0.36±0.01	0.26±0.01
Phosphorus (kg/ha.)	35±0.37	41±0.22	30±0.20	34±0.33
Photas (kg/ha.)	310±1.71	410±1.80	360±1.45	260±1.35
Zinc (ppm)	0.90±0.02	0.84±0.03	0.80±0.01	0.81±0.01
Iron (ppm)	4.90±0.03	4.96±0.01	4.91±0.02	4.00±0.01
Copper (ppm)	0.40±0.02	0.44±0.01	0.49±0.01	0.35±0.02
Manganese (ppm)	3.11±0.01	3.98±0.03	3.18±0.02	3.91±0.01
Sulpur (ppm)	14±0.40	19±0.45	16±0.40	18±0.40

Table 2. Arthropod diversity under Prosopis cineraria

Class	Order	Family	Individualas	% Over Total Count
Insecta	1.Diptera	Cecidomycidae,Calliphoridae,Muscidae,Psychodidae,Drosophilidae,Anthomyiidae	39	17.64%
	2. Hymenoptera	Apidae,Torymidae,Ormyridae, Stephenidae,Eulophidae,,Formicidae	20	9.04%
	3.Hemiptera	Miridae,Coreidae,Cieadellidae	17	7.69%
	4.Coleoptera	Anthicidae,Burprestidae,Dermistedae	16	7.23%
	5.Lepidoptera	Noctuidae,Hesperiidae, Lasiocampidae, Lycaenidae	15	6.78%
	6.Blattodea	Blattidae	12	5.4%
Arachnida	1. Parasitiformes	Macrochelidae	34	15.38%
	2. Mesostigmata	Phytoseiidae	22	9.95%
	3.Araneae	Scytodidae,Oxyopidae, Philodro midae	15	6.78%
Collembola	1.Entomobryomorpha	Isomidae	31	14.07%
Total			221	

Table 3. Arthropod diversity under Azadirachta indica

Class	Order	Family	individuals	% Over Total Count
Insecta	1.Diptera	Culicidae,Cecidomyiidae, Sciaridae,Psychodidae	32	13.91%
	2. Hymenoptera	Formicidae	22	9.56%
	3. Blattodea	Blattidae	15	6.52%
	4.Hemiptera	Miridae,Coreidae,cleadellidae	12	5.21%
	5.Coleoptera	Leiodidae,Ptillidae	11	4.78%
Arachnida	1. Mesostigmata	Phytoseiidae	40	17.39%
	2.Araneae	Lycocidae,scytodidae, Oxyopidae	28	12.17%
	3. Parasidiformes	Macrochelidae	25	10.86%
	4.Opiliones	Sclerosomatidae	10	4.34%
Collembola	1.Entomobryomorpha	Isotomidae	35	15.21%
Total			230	

Table 4. Arthropod diversity under Tecomella undulata

Class	Order	Family	Individuals	% Over Total Count
Insecta	1.Hemiptera	Pantatomidae,Alydidae, Rhyparochromidae	24	15.09%
	2. Diptera	Psychodidae,Musidae,Drosophilidae	22	13.83%
	3. Hymenoptera	Formicida	20	12.57%
	4.Orthoptera	Acrididae,Gryllidae	16	10.06%
	5.Blattodea	Blattidae,Termitidae	12	7.54%
	6. Coleoptera	Scarabaeidae	8	5.03%
Aracnida	1. parasitiformes	Macrochelidae	25	15.75%
	2. Mesostigmata	Phytoseiidae	17	10.69%
Collembola	1.Entomobryomorpha	Isotomidae	15	9.43%
Total			159	

Table 5. Arthropod diversity in an open agricultural field				
Class	**Order**	**Family**	**Individuals**	**% Over Total Count**
Insecta	1.Hemiptera	Lygaeidae,Pyrrhocoridae,Pentatomidae,Dinidoridae	16	15.84%
	2. Diptera	Culicidae,Psychodidae	15	14.85%
	3.Orthoptera	Gryllidae,Acrididae	13	12.87%
	4.Coleoptera	Tenebrionidae	7	6.93%
Arachnida	1. Araneae	Scytodidae, Oxyopidae, Philodromidae,	20	19.80%
	2. Parasitiformes	Macrochelidae	10	9.90%
	3.Opiliones	Sclerosomatidae	9	8.91%
Collembola	1.Entamobryomorpha	Isotimidae	11	10.89%
Total			101	

Table 6. Species diversity and species richness indices				
Indices	**Shanon H'**	**Pielo's evenness**	**Simpson1-D**	**Margalef DMg**
Prosopis cineraria	2.23	0.97	0.884	1.67
Azadirachta indica	2.19	0.96	0.886	1.66
Tecomella undulata	2.14	0.97	0.879	1.57
Open agricultural field	2.02	0.97	0.885	1.52

RESULTS AND DISCUSSION

Soil fertility indicators such as organic carbon, phosphorus, and moisture content showed a positive correlation with soil arthropod abundance and diversity. The accumulation of litter and root biomass beneath tree cover created favorable microclimatic conditions that supported nutrient cycling through the activity of detritivores and predators. Among the soil mesofauna, groups such as Acari and Collembola, along with macrofaunal orders including Hymenoptera, Orthoptera, Diptera, and Coleoptera, were the most prominent biotic components recorded. These organisms play vital roles in biological processes within the rhizosphere and the surrounding environment by facilitating decomposition of organic matter.

The field investigation across tree-covered sites in the erstwhile Nizamabad District, Telangana revealed significant differences in both soil arthropod abundance and soil fertility parameters compared to adjacent open agricultural fields. Soil pH was relatively uniform across all sites, ranging between 8.1 and 8.2, indicating slightly alkaline conditions. Organic carbon and potassium exhibited a strong positive correlation with arthropod presence. Since these nutrients are essential for plant health and productivity, they indirectly promote larger and more diverse arthropod populations by increasing plant biomass and habitat heterogeneity.

A significant positive correlation was observed between arthropod diversity and key soil fertility parameters. Arthropod activities such as litter fragmentation, burrowing, and bioturbation enhanced soil aeration, water infiltration, and nutrient cycling. As hypothesized, higher arthropod abundance was recorded under tree cover compared to the open agricultural field. Across all sites, three classes of arthropods were documented: Insecta, Arachnida, and Collembola. The dominant class was Insecta, comprising 53.84% under Prosopis cineraria, 40% under Azadirachta indica, 64.15% under Tecomella undulata, and 50.49% in the open agricultural field. Within the Insecta class, the highest representation was from the orders Diptera and Hymenoptera.

The relative abundance of Arachnida and Collembola varied with habitat type. Under Prosopis cineraria, Arachnida accounted for 32.12% and Collembola 14.02% of the arthropod population. In Azadirachta indica, Arachnida made up 44.78% and Collembola 15.28%. In Tecomella undulata, the respective proportions were 18.26% for Arachnida and 9.43% for Collembola. In the open agricultural field, Arachnida represented 38.61% while Collembola accounted for 10.89% of the community.

Diversity indices further highlighted the impact of tree cover. The Shannon Index (H′), which integrates species richness and relative abundance, was highest under Prosopis cineraria (2.23), followed by Azadirachta indica (2.19), Tecomella undulata (2.14), and the open agricultural field (2.02). This indicates greater species diversity under tree cover and reduced diversity in open fields. Pielou's Evenness Index values were relatively uniform: 0.97 for Prosopis cineraria, 0.96 for Azadirachta indica, 0.97 for Tecomella undulata, and 0.97 for the open agricultural field, reflecting balanced species distribution across sites. Simpson's Index (1–D) values were also high, with 0.884 for Prosopis cineraria, 0.886 for Azadirachta indica, 0.879 for Tecomella undulata, and 0.885 for the open agricultural field, indicating overall higher diversity across systems. Margalef's Species Richness Index (DMg) was 1.67 for Prosopis cineraria, 1.66 for Azadirachta indica, 1.57 for Tecomella undulata, and 1.52 for the open agricultural field, showing that Prosopis cineraria supported the greatest species richness, while open fields exhibited the lowest, likely due to reduced microhabitat availability and frequent human disturbance.

The results emphasize that increasing tree cover in agricultural landscapes enhances arthropod diversity and significantly improves ecosystem functions. Leaf litter inputs and root exudates act as critical food resources, stimulating microbial activity and indirectly supporting soil arthropod communities. Tree cover also creates a stable microclimate with moderated temperatures and consistent organic matter inputs through litter fall. These conditions favor the proliferation of soil arthropods, which in turn accelerate litter decomposition and nutrient cycling. The positive correlation between arthropod diversity and soil fertility indicators demonstrates that conserving tree cover not only maintains biodiversity but also sustains soil health. Thus, tree arthropod interactions contribute directly to long-term soil sustainability.

CONCLUSION

The present study underscores the vital role of tree cover in sustaining soil arthropod diversity and abundance in Nizamabad, Telangana. Tree-covered sites supported a richer arthropod community by providing favorable microclimatic conditions, organic matter inputs, and greater habitat complexity. These organisms, through litter decomposition, nutrient cycling, and improvement of soil structure, significantly contribute to soil fertility and agro ecosystem sustainability. In contrast, open agricultural fields with limited organic inputs and harsher soil conditions exhibited reduced arthropod populations. The findings emphasize the ecological significance of conserving and expanding tree cover to maintain soil health and biodiversity. Integrating agro forestry and tree-based land-use practices into agricultural systems can serve as a practical strategy for ensuring long-term soil fertility and sustainable crop production in semi-arid regions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) affirm that no generative AI technologies, including Large Language Models (e.g., Chat GPT, Copilot) or text-to-image tools, were used in the preparation, analysis, or editing of this manuscript.

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COMPETING INTERESTS

The author declares that there are no competing interests related to this work.

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