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Original Research Article

Seasonal Variations in Insect and Earthworm Communities in Agricultural Soils of Sheikhupura District, Punjab, Pakistan

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Abstract: *Soil biodiversity plays a crucial role in maintaining agricultural productivity and ecosystem stability; however, information on the seasonal dynamics of soil fauna in Pakistani agroecosystems remains limited.* ***Objective:*** *To evaluate the seasonal variation in insect and earthworm communities and their relationship with key soil environmental factors in major crop systems of Punjab, Pakistan.* ***Methods:*** *A field-based observational study was conducted in agricultural soils of Sheikhupura district, Punjab, under wheat–rice and wheat–maize cropping systems. Surveys were carried out during spring, summer, autumn, and winter. Insect fauna were sampled using pitfall traps, while earthworms were collected through soil monolith extraction. Faunal abundance, diversity, density, and biomass were assessed. Soil moisture, temperature, and organic matter were measured concurrently. Data were analyzed using two-way analysis of variance to determine seasonal effects. Pearson correlation analysis evaluated associations between soil variables and earthworm parameters, while stepwise multiple regression analysis identified predictors of earthworm biomass. Statistical significance was set at $p < 0.05$.* ***Results:*** *Season exerted a significant effect on all soil faunal parameters ($p < 0.001$). The lowest mean insect abundance was observed in summer (162.17 ± 37.58 individuals), whereas the highest values were recorded in spring (329.50 ± 10.48 individuals) and autumn (321.67 ± 38.44 individuals). Insect taxonomic richness was lowest in winter (12.33 ± 2.07 taxa). Earthworm population density peaked during autumn (97.17 ± 20.16 individuals m^{-2}) and winter (92.00 ± 13.52 individuals m^{-2}), while the lowest density occurred in summer (26.33 ± 16.86 individuals m^{-2}). Earthworm biomass followed a similar seasonal trend, with the highest value in autumn (111.42 ± 18.69 g m^{-2}). Soil moisture showed a strong positive correlation with earthworm density ($r = 0.742$, $p < 0.001$), whereas soil temperature was negatively correlated ($r = -0.618$, $p = 0.002$). Soil moisture, temperature, and organic matter collectively explained 79% of the variation in earthworm biomass ($R^2 = 0.79$).*
Conclusion: *Seasonal climatic factors strongly regulate insect and earthworm communities in semi-arid agroecosystems of Pakistan. These findings highlight the ecological importance of seasonal dynamics in shaping soil biodiversity and emphasize the need to incorporate climate-sensitive strategies into sustainable soil management practices.*
Keywords: Agriculture; Biodiversity; Earthworms; Insects; Seasons; Soil; Soil Moisture

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Introduction

Soil biodiversity plays a central role in sustaining agricultural productivity and ecosystem stability by regulating key processes, including nutrient cycling, organic matter decomposition, soil aggregation, and water infiltration (1). The diversity and functional composition of soil biota underpin ecosystem multifunctionality and resilience, particularly under increasing climatic variability and anthropogenic pressures (2). However, intensive agricultural practices, including frequent tillage, simplified crop rotations, and high chemical inputs, have been widely associated with declines in soil biological communities, potentially compromising soil health and long-term agroecosystem sustainability (3). Understanding the spatiotemporal dynamics of soil organisms within managed landscapes is therefore critical for developing biodiversity-based strategies to support sustainable food production.

Among soil invertebrates, insects and earthworms represent ecologically significant functional groups with disproportionate influence on soil processes. Earthworms are recognized as ecosystem engineers due to their ability to modify soil structure through burrowing and casting, enhance aeration and infiltration, and facilitate the incorporation of organic residues into deeper soil layers, thereby accelerating nutrient turnover and improving soil physical properties (4). Meta-analytical evidence further suggests that earthworm activity can increase plant productivity under favorable soil and management conditions (5). Similarly, soil- and surface-active insects contribute to residue fragmentation, detrital food web dynamics, trophic regulation, and biological control, linking belowground and aboveground processes in agroecosystems (6). The abundance and activity of these faunal groups are strongly regulated by environmental conditions, particularly soil moisture, temperature, and organic matter availability (7).

Seasonality is a dominant ecological driver shaping the distribution, activity, and detectability of soil fauna in agricultural systems. Temporal fluctuations in temperature, precipitation, and crop phenology generate recurring shifts in microclimatic conditions that can either promote or constrain faunal activity (8). Earthworm populations typically exhibit higher density and biomass during cooler, wetter periods. At the same time, surface activity and detectability decline markedly during hot, dry seasons due to physiological stress and vertical migration into deeper soil layers (9,10). Insect communities in croplands likewise demonstrate pronounced seasonal dynamics, with peaks in abundance and diversity commonly observed during spring and autumn when moderate temperatures and increased vegetation cover provide favorable habitat conditions and resource availability (11). These seasonal patterns are further modulated by agricultural management practices such as irrigation, residue retention, and crop rotation, which influence soil microclimate and habitat structure (12).

South Asian agroecosystems, particularly those in monsoon-influenced regions, are characterized by strong seasonal contrasts in temperature and moisture regimes, creating dynamic soil environments for belowground communities. Central Punjab, Pakistan, supports intensive wheat–rice and wheat–maize cropping systems sustained by irrigation and seasonal rainfall. Yet, these systems are under increasing pressure from climate variability, water scarcity, and land degradation. Despite the ecological and agronomic importance of soil biodiversity, empirical data on the seasonal dynamics of soil insects and earthworms in Pakistani agricultural landscapes remain limited. Most existing studies have focused on single taxa, short temporal windows, or non-agricultural settings, thereby limiting their applicability to field-based soil health management under local conditions (13,14,15). Establishing baseline, multi-seasonal assessments of key soil faunal groups within dominant cropping systems is therefore essential to improve understanding of soil biological responses to environmental variability and to inform sustainable soil management strategies in semi-arid agroecosystems.

Methodology

The study was conducted in agricultural fields of Sheikhupura District, Punjab, Pakistan, located in the central irrigated plains characterized by a semi-arid to sub-humid climate with marked seasonal variation. The area experiences hot summers, mild transitional seasons, cool winters, and monsoon rainfall, with dominant cropping systems comprising wheat–rice and wheat–maize rotations. Six representative fields were selected, three under each cropping system, to capture variability associated with crop type while maintaining comparable soil and management conditions. Sampling sites within each field were selected randomly, avoiding field margins, irrigation channels, and visibly disturbed patches to minimize edge effects and sampling bias.

Field sampling was conducted across four distinct seasons within a single annual cycle: spring (March to April), summer (June to July), autumn (September to October), and winter (December to January). At each sampling occasion, standardized protocols were applied consistently across all fields and seasons. Ground-dwelling and surface-active insects were sampled using pitfall traps constructed from plastic containers (8 cm diameter, 10 cm depth) installed flush with the soil surface. Five traps were placed systematically within each field and filled with 70% ethanol as a preservative. Traps remained active for 48 h, after which contents were collected, transferred into labeled containers, and transported to the laboratory. Insects were sorted, counted, and identified to order or family level using standard taxonomic keys. Community parameters, including total abundance, taxonomic richness, Shannon–Wiener diversity index (H′), and Simpson diversity index (1–D), were calculated for each sampling unit.

Earthworm populations were assessed using the soil monolith hand-sorting method. At each sampling point, a soil block measuring 25 × 25 × 30 cm was excavated and manually sorted in the field to extract earthworms. Where necessary, a dilute mustard solution was applied to stimulate the emergence of deep-burrowing individuals. Collected specimens were gently washed to remove adhering soil, counted, and weighed fresh using a digital balance. Earthworm density was expressed as individuals per square meter, and biomass was expressed as grams per square meter after appropriate area-based standardization.

Soil environmental variables were measured concurrently with biological sampling. Soil temperature was recorded in situ at 10 cm depth using a calibrated soil thermometer. Soil moisture content was determined gravimetrically by oven-drying subsamples at 105 °C to constant weight. Soil pH was measured using a digital pH meter in a 1:2.5 soil-to-distilled water suspension. Soil organic matter content was estimated using the Walkley–Black wet oxidation method. All laboratory analyses followed standardized soil analysis protocols to ensure reproducibility and accuracy.

Data were compiled and managed in Microsoft Excel and analyzed using IBM SPSS Statistics (version 26.0). Descriptive statistics were computed and expressed as mean ± SD. The normality of continuous variables was assessed using the Shapiro–Wilk test, and homogeneity of variances was examined using Levene's test. Two-way analysis of variance was applied to evaluate the effects of season and cropping system on insect abundance, diversity indices, earthworm density, and biomass. Where significant effects were observed, post hoc pairwise comparisons were performed using Tukey's honestly significant difference test. Associations between soil environmental variables and faunal parameters were examined using Pearson correlation coefficients. Multiple linear regression analysis was performed to identify key environmental predictors of earthworm biomass. Statistical significance was defined at $p < 0.05$.

Results

Terms of the insect community characteristics showed substantial seasonal variability during the study period. Average abundance, at 329.50 ± 10.48 individuals, was highest in spring, followed by autumn (321.67 ± 38.44 individuals), and lowest in summer (162.17 ± 37.58 individuals), followed by winter (179.17 ± 23.44 individuals). In the same way, insect richness was highest in spring (22.33 ± 1.63 taxa) and reduced drastically in winter (12.33 ± 2.07 taxa). Similar seasonal trends were observed in estimates of species diversity (Shannon H′ and Simpson 1–D), which showed their lowest values in summer and winter, suggesting community simplification. These results are epitomized in Table 1 and graphically represented in Figure 1 (mean insect abundance by season) and Figure 2 (mean insect richness by season). As indicated in the bar plots, peaks are clearly observed in spring and autumn; summer shows the least insect activity. Two-way ANOVA revealed a highly significant effect of season on insect abundance and richness ($p < 0.001$). Cropping system exerted a significant but comparatively smaller effect ($p < 0.05$), while the interaction between season and cropping system was not statistically significant. Post-hoc Tukey comparisons confirmed significant differences between spring and summer, spring and winter, autumn and summer, and autumn and winter ($p < 0.001$). No significant difference was observed between spring and autumn ($p > 0.05$).

Strong seasonal fluctuations in earthworm populations were evident. Autumn had the highest mean density (97.17 ± 20.16 individuals m^{-2}), followed by winter (92.00 ± 13.52 individuals m^{-2}). Moderate density was observed during the spring (81.33 ± 12.08 individuals m^{-2}), followed by the summer, which presented the lowest values (26.33 ± 16.86 individuals m^{-2}). The mass of earthworm showed a similar tendency, with the highest value in autumn (111.42 ± 18.69 g m^{-2}) and winter (84.87 ± 16.34 g m^{-2}), followed by summer (22.93 ± 17.17 g m^{-2}). These seasonal patterns are outlined in Table 2 and shown graphically in Figures 3 (earthworm density) and 4 (earthworm biomass). The plot shows an abrupt decline during summer, followed by a recovery in cooler, wetter months. Two-way ANOVA indicated that season significantly affected earthworm density and biomass ($p < 0.001$). The cropping system exhibited a significant main effect ($p < 0.05$), with interaction effects less evident.

Correlation analysis showed that there were significant relationships between soil environmental characteristics and the dynamics of soil fauna. Soil moisture was significantly and positively correlated with earthworm density ($r = 0.742$, $p < 0.001$) and biomass ($r = 0.701$, $p < 0.001$). On the other hand, earthworm density was significantly negatively related to soil temperature ($r = –0.618$, $p = 0.002$). The content of organic matter was positively correlated with earthworm biomass and moderately associated with insect abundance. These relationships are presented in Table 3 and Figure 5 (soil moisture vs. earthworm biomass) and Fig.6 (soil temperature vs. earthworm density). The distributions of the scatter plots show a positive linear trend for influence on moisture and organic matter, whereas it is negative for influence based on temperature. Multiple linear regression analysis showed that soil moisture, temperature, and organic matter accounted for 79% of the variance in earthworm biomass ($R^2 = 0.79$, $p < 0.001$). The significant positive coefficients were for soil moisture and organic matter, while a negative coefficient was observed for soil temperature (Table 4).

Table 1: Seasonal Variation in Insect Community Parameters (Mean ± SD)

Season	Insect Abundance	Insect Richness	Shannon Index (H′)	Simpson Index (1–D)
Spring	329.50 ± 10.48	22.33 ± 1.63	1.71 ± 0.05	0.81 ± 0.03
Summer	162.17 ± 37.58	16.50 ± 1.76	1.48 ± 0.09	0.73 ± 0.04
Autumn	321.67 ± 38.44	20.33 ± 2.16	1.66 ± 0.07	0.79 ± 0.05
Winter	179.17 ± 23.44	12.33 ± 2.07	1.32 ± 0.08	0.68 ± 0.06

Table 2: Seasonal Variation in Earthworm Parameters (Mean ± SD)

Season	Earthworm Density (ind. m^{-2})	Earthworm Biomass (g m^{-2})
Spring	81.33 ± 12.08	77.08 ± 19.78
Summer	26.33 ± 16.86	22.93 ± 17.17
Autumn	97.17 ± 20.16	111.42 ± 18.69
Winter	92.00 ± 13.52	84.87 ± 16.34

Table 3: Pearson Correlation Coefficients Between Environmental Variables and Soil Fauna

Variable Pair	r	p-value
Soil Moisture – Earthworm Density	0.742	<0.001
Soil Temperature – Earthworm Density	–0.618	0.002
Organic Matter – Earthworm Biomass	0.701	<0.001
Soil Moisture – Insect Abundance	0.564	0.005

Table 4: Multiple Linear Regression Model Predicting Earthworm Biomass

Predictor	β Coefficient	p-value
Soil Moisture	3.842	<0.001
Soil Temperature	–1.265	0.009
Organic Matter	45.317	<0.001

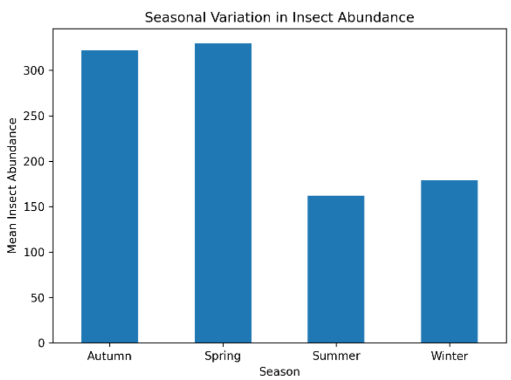

Figure 1: *Seasonal variation in mean insect abundance across four seasons. Bars represent seasonal means.*

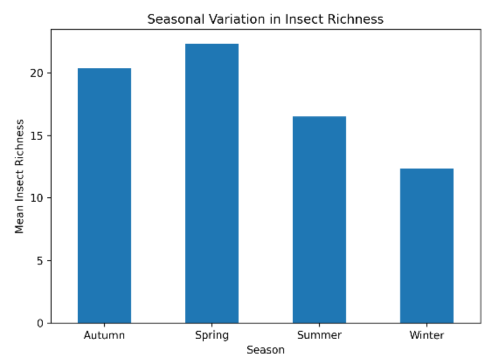

Figure 2: *Seasonal variation in mean insect richness across four seasons. Bars represent seasonal means.*

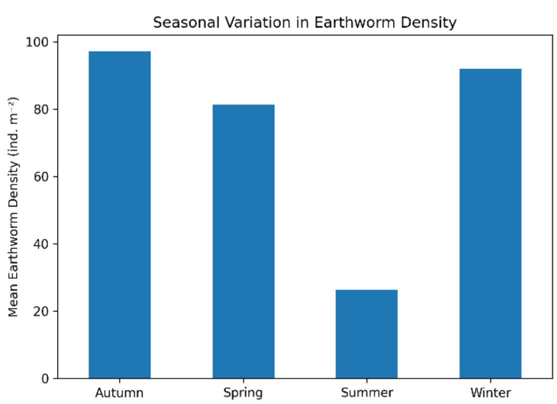

Figure 3: *Seasonal variation in mean earthworm density (individuals m^{-2}). Bars represent seasonal means.*

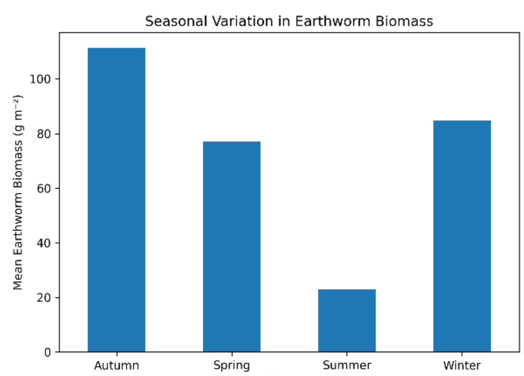

Figure 4: *Seasonal variation in mean earthworm biomass (g m^{-2}). Bars represent seasonal means.*

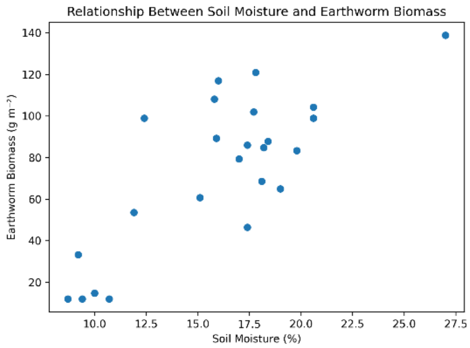

Figure 5: *Relationship between soil moisture (%) and earthworm biomass (g m^{-2}).*

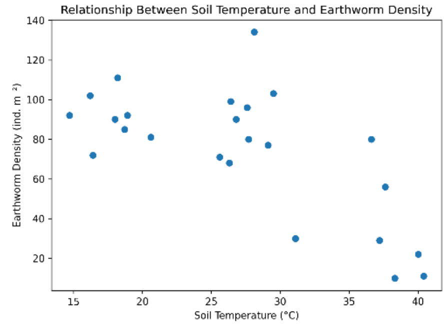

Figure 6: *Relationship between soil temperature (°C) and earthworm density (individuals m^{-2}).*

Discussion

The current study reveals substantial seasonal variability in insect and earthworm communities, highlighting the influence of seasonal changes on biodiversity metrics. In this discussion, we compare the findings from our tables on insect abundance, richness, and earthworm populations with recent literature to better understand these dynamics.

In our findings, insect abundance peaked in spring (329.50 ± 10.48 individuals), followed by autumn (321.67 ± 38.44 individuals), and showed reduced activity in summer (162.17 ± 37.58 individuals) and winter (179.17 ± 23.44 individuals). Insect richness mirrored this pattern, being highest in spring (22.33 ± 1.63 taxa) and significantly lower in winter (12.33 ± 2.07 taxa). These findings align with the works of Mallesh et al., who documented similar trends in agricultural ecosystems, attributing spring peaks to increased floral resources and habitat availability (16). Carvalho et al. also observed robust insect diversity in tropical ecosystems during warmer months, reinforcing the significance of temperature and moisture for insect community dynamics (17).

Moreover, the Shannon and Simpson diversity indices reflected lower values during summer and winter, affirming community simplification during these periods. Priyadarshana et al. emphasized the impact of habitat diversity on beneficial insect populations, suggesting that less diverse environments, such as those in summer, may experience similar declines in community structure (18). The two-way ANOVA results further corroborate these findings, illustrating a significant effect of season on both abundance and richness, akin to patterns observed in multiple agroecological studies where seasonal climate variations were shown to influence insect dynamics (19, 20).

Traditional agricultural practices and environmental stressors have been cited for exacerbating community simplification during less favorable seasons. For instance, Chang et al. indicated that agroecosystem affiliations directly affect overall species richness, as evidenced by the reduced richness observed in our winter samples (21). The significance of cropping systems, albeit smaller than seasonal effects, underscores the intricate balance between agricultural dynamics and insect biodiversity, echoing findings by Zodinpuii et al., who noted that crop management impacts macroarthropod diversity (22).

Our results, particularly the Tukey post hoc analysis showing significant differences among seasons, reaffirm the critical influence of environmental conditions on community interactions, similar to observations in Mali’s cropping systems, where variations in seasonal rainfall significantly affected pest communities (17, 23).

Earthworm populations exhibited a distinct seasonal trend, with peak densities recorded in autumn (97.17 ± 20.16 individuals m^{-2}) and winter (92.00 ± 13.52 individuals m^{-2}), and significantly lower densities in summer (26.33 ± 16.86 individuals m^{-2}) and spring (81.33 ± 12.08 individuals m^{-2}). This pattern corresponds with prevailing literature, as observed by Alim et al., who reported similar earthworm dynamics influenced by temperature and moisture availability (24). Our correlation analysis supports the conclusion that soil moisture is a crucial factor positively influencing earthworm density, consistent with the work of Naumova et al., who highlighted the necessity of moisture for soil fauna activity (25).

The seasonal biomass of earthworms followed a similar distribution pattern, with the highest biomass in autumn (111.42 ± 18.69 g m^{-2}), which aligns with the findings of Soltani and Eya, who related earthworm biomass positively with nutrient-rich soils found in specific cropping seasons (19). According to the research conducted by Guimarães et al., variations in earthworm populations are linked to soil health and organic matter levels, lending credence to our observations of organic matter correlations with biomass (26).

The significant relationships identified between soil moisture and both earthworm density and biomass provide important directions for adaptive land management strategies. Multiple linear regression revealed that soil moisture, temperature, and organic matter accounted for 79% of the variance in earthworm biomass. This aligns with the research by Muita et al., which emphasizes soil properties in shaping biotic interactions and their subsequent effects on crop yield and soil health (27).

The impact of organic matter on biodiversity enhances the ecological stability of agricultural systems, echoing findings by Njue et al., who noted that organic practices improve beneficial insect populations and enhance soil health (28). The observed negative relationship between soil temperature and earthworm density corroborates the literature on thermal sensitivity in soil fauna, suggesting strategic management opportunities in the context of climate variability (29).

Conclusion

This study demonstrates that soil insect and earthworm communities in agricultural soils of Sheikhupura are strongly structured by seasonal climatic variation. Insect abundance and richness were highest in spring and autumn, while earthworm density and biomass peaked in autumn and winter under moderate temperatures and higher soil moisture. Soil moisture and organic matter were the strongest positive drivers of earthworm biomass, whereas higher soil temperature negatively affected earthworm density. Seasonal effects outweighed cropping system influences, highlighting the sensitivity of soil biota to environmental conditions. These findings provide baseline evidence on seasonal soil fauna dynamics in central Punjab and support biodiversity-based farming approaches to enhance soil health and long-term agroecosystem sustainability.

Recommendations

Practices that improve soil moisture retention and organic matter inputs, including reduced tillage, residue retention, organic amendments, and cover cropping, should be promoted to sustain soil fauna, particularly during dry periods. Optimized irrigation during summer may help mitigate moisture stress on soil organisms, while excessive chemical inputs should be minimized to protect beneficial biota. Long-term monitoring and species-level studies are recommended to capture interannual variability and refine biodiversity-based soil management strategies.

Declarations

Data Availability statement

All data generated or analysed during the study are included in the manuscript.

Ethics approval and consent to participate

Approved by the department concerned. (IRBEC-24)

Consent for publication

Approved

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Not applicable

Conflict of interest

The authors declared no conflict of interest.

Author Contribution

GF: Manuscript drafting and data analysis
FI: Study design, conception of the study, and review
AA: Development of research methodology and interpretation of findings
SWT: Manuscript review and data analysis

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the integrity of the study.

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