**Ecology of Soil-Dwelling Insects and Their Influence on Crop Health: A Review**

**Abstract**

Soil-dwelling insects play indispensable roles in regulating soil health, nutrient cycling, plant productivity, and ecological stability within agroecosystems. As integral components of the soil food web, these organisms function as decomposers, herbivores, predators, mutualists, and bioindicators, facilitating organic matter breakdown, microbial regulation, and natural pest suppression. Their habitat preferences, vertical stratification, and functional niches are governed by soil moisture, texture, organic content, and vegetation diversity. Through litter fragmentation and bioturbation, insects like termites, beetles, and ants enhance soil aggregation, aeration, and nutrient mobilization, directly influencing crop health and yield. Interactions with microbes, nematodes, and rhizosphere communities further extend their ecological relevance, promoting microbial diversity and inducing plant defence pathways. Anthropogenic pressures such as tillage, pesticide application, habitat loss, and climate-induced shifts in temperature and precipitation regimes significantly alter their diversity, abundance, and functionality. Invasive soil insects and changing geographical distributions exacerbate pest risks and ecological imbalances. Conservation agriculture practices, agroecological interventions, habitat engineering, and the use of insect-based biofertilizers and biocontrol agents offer sustainable pathways to enhance beneficial soil insect functions. Molecular tools like DNA metabarcoding and soil metagenomics are advancing the resolution and scope of insect diversity assessments, while long-term multi-scalar research remains crucial for understanding their systemic impacts. Soil insects also exhibit strong potential as ecological indicators of land degradation, pollution, and agricultural sustainability due to their sensitivity to environmental stressors and ecosystem alterations. Integrating soil entomology into modern agricultural frameworks and policy planning is critical for developing resilient and productive agroecosystems under the pressures of intensification and climate change.

**Keywords:** *Soil Insects, Nutrient Cycling, Bioturbation, Agroecosystem Health, Pest Regulation, Ecological Indicators*

**I. Introduction**

*A. Importance of soil biodiversity in agroecosystems*
Soil biodiversity forms the foundation of terrestrial ecosystems, supporting vital functions like nutrient cycling, organic matter decomposition, and disease suppression (Sylvain *et.al.,* 2011). It includes an intricate network of organisms such as bacteria, fungi, protozoa, nematodes, and soil-dwelling arthropods. Soil-dwelling insects constitute a significant component of this biodiversity, contributing to the structural and functional stability of soils. Global studies have shown that agroecosystems with higher belowground diversity are more resilient to stress, offering better crop productivity and environmental sustainability.

*B. Role of soil-dwelling insects in ecosystem functions*
Soil insects such as beetles (Coleoptera), ants (Formicidae), termites (Isoptera), and springtails (Collembola) engage in complex ecological interactions (Menta *et.al.,* 2020). These organisms are responsible for aerating soil, fragmenting organic matter, and facilitating microbial colonization, which accelerates nutrient mineralization. Termites and dung beetles, for instance, contribute to rapid incorporation of organic residues, improving soil structure and porosity. Predatory insects such as carabids help regulate soil-dwelling pests, while pollinating insects nesting in soil enhance aboveground plant reproductive success. Their combined activities support agroecosystem services that are crucial for both natural and managed landscapes (Verma *et.al.,* 2023).

**II. Classification and Functional Groups of Soil-Dwelling Insects**

*A. Taxonomic classification of soil insects*
Soil-dwelling insects encompass several taxonomic orders, each exhibiting distinct ecological (Table 1) roles (Verma *et.al.,* 2023). Key taxa include Coleoptera (e.g., Carabidae, Scarabaeidae), Hymenoptera (Formicidae), Isoptera (termites), Orthoptera (e.g., Gryllidae), Diptera (larval stages of Sciaridae, Tipulidae), and Collembola (springtails, often considered basal hexapods). Carabids are often used as bioindicators due to their sensitivity to land-use changes. Ants serve as ecosystem engineers, altering soil chemistry and structure. Termites, especially members of the Termitidae family, dominate tropical soil insect biomass and are responsible for extensive bioturbation. Each order contributes uniquely to soil structure, organic matter turnover, and biocontrol processes.

*B. Functional groups: decomposers, herbivores, predators, pollinators, parasites*
Soil insects are categorized into functional groups based on their ecological roles:

*Decomposers*: Termites, saprophagous beetles, and Collembola consume decaying organic matter, facilitating microbial breakdown and nutrient release (Bagyaraj *et.al.,* 2016).

*Herbivores*: Root-feeding insects such as wireworms (Elateridae larvae) and root weevils (Curculionidae) damage crop roots, affecting plant water and nutrient uptake.

*Predators*: Ground beetles (Carabidae) and rove beetles (Staphylinidae) prey on soil pests including aphids, mites, and larval forms, contributing to natural pest regulation.

*Pollinators*: Certain solitary bees (e.g., Andrenidae) and wasps nest in the soil and support aboveground pollination networks, indirectly affecting crop yields.

*Parasites*: Parasitic wasps and flies target pest larvae or eggs within the soil, serving as biocontrol agents in integrated pest management systems (Dunn *et.al.,* 2020).

*C. Trophic interactions and energy flow in soil food webs*
Soil insects are central to belowground food webs, acting as both prey and predators in dynamic trophic linkages. Primary decomposers like Collembola feed on fungi and litter, forming a base for higher trophic levels. Secondary consumers such as predatory beetles and parasitic wasps regulate herbivores and decomposers, maintaining trophic balance. Trophic cascades in soil are modulated by abiotic factors like moisture and temperature, and by biotic interactions involving microbes and plant roots. Energy flow in soil food webs is influenced by detritus availability and insect-mediated nutrient transformation processes, which shape soil fertility and plant performance.

**Table:1** Classification and Functional Groups of Soil-Dwelling Insects (Source- Verma *et.al*., 2023)

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Insect Group** | **Examples** | **Primary Function/Role in Soil** |
| **Decomposers/Detritivores** | Springtails, Beetle larvae, Fungus gnats | *Collembola*, *Scarabaeidae*, *Sciaridae* | Breakdown of organic matter, nutrient cycling |
| **Predators** | Ground beetles, Rove beetles, Ants | *Carabidae*, *Staphylinidae*, *Formicidae* | Regulate pest populations, trophic balance |
| **Herbivores/Root Feeders** | Root maggots, Wireworms, White grubs | *Delia spp.*, *Agriotes spp.*, *Phyllophaga spp.* | Feed on roots, reduce plant vigor and yield |
| **Pollinators (Soil Nesters)** | Solitary bees | *Andrena spp.*, *Halictus spp.* | Nest in soil, aid in plant pollination |
| **Ecosystem Engineers** | Termites, Ants, Earth-boring beetles | *Termitidae*, *Formicidae*, *Geotrupidae* | Improve soil aeration, structure, organic matter movement |
| **Parasitoids** | Parasitic wasps (soil pupation stages) | *Braconidae*, *Ichneumonidae* | Biological control of pests developing underground |
| **Pathogen Vectors** | Some beetles and flies | *Elateridae*, *Tipulidae* | Transmit soil-borne pathogens to crops |

**III. Habitat Preferences and Ecological Niches**

*A. Vertical and horizontal stratification in soil profiles*
Soil-dwelling insects exhibit distinct vertical and horizontal stratification patterns in response to variations in moisture, temperature, oxygen concentration, and food availability across soil layers (Lavelle *et.al.,* 2001). Macrofauna such as beetle larvae and ants often dominate the top 0–10 cm of soil, while termites and some isopods extend their foraging activities deeper into the subsoil, particularly in tropical systems. The stratification is dynamic and can shift seasonally or under changing land-use pressures. Horizontal distribution is often patchy due to localized nutrient concentrations or microhabitat heterogeneity. These patterns are critical for regulating decomposition gradients and belowground ecological interactions. Sampling studies conducted in maize and wheat agroecosystems have recorded significant shifts in insect density and diversity between root zones and inter-row spaces (Fiera et.al., 2020).

*B. Microhabitat characteristics influencing insect diversity*
Soil insect diversity is strongly influenced by microhabitat variables such as organic matter content, litter thickness, pH, porosity, and vegetation type. Leaf litter provides essential shelter and food for decomposers like Collembola and dipteran larvae. Termites and ants often modify their microhabitats by constructing elaborate galleries and mounds, altering moisture retention and nutrient cycling (Ali *et.al.,* 2013). Structural complexity from root systems, rhizodeposition, and fungal networks creates ecological niches supporting high insect diversity. Diversity tends to decline in compacted or heavily irrigated soils due to oxygen limitation and physical barriers to movement.

*C. Interactions with soil physico-chemical properties*
Soil pH, moisture, temperature, and nutrient levels shape insect abundance and community composition. Acidic soils typically harbour higher densities of Collembola and enchytraeids, while neutral to alkaline soils support more beetles and ants. Soil texture plays a pivotal role in determining the burrowing capacity of insects. Sandy soils, with larger pore spaces, allow better movement and colonization by fast-moving predators like carabids, while clay-rich soils favor detritivores like isopods due to moisture retention. Organic matter serves as a critical driver for insect biomass, correlating positively with microbial activity and root exudation (Potapov *et.al.,* 2017).

**IV. Life Cycle Strategies and Adaptations**

*A. Seasonal and developmental patterns*
Many soil insects display seasonal life cycle adjustments to align development with favourable soil conditions. For example, wireworms (Agriotes spp.) exhibit multi-year larval stages, with peak activity during spring and autumn due to optimal temperature and soil moisture. Termites often synchronize colony expansion and foraging with monsoon periods to exploit decaying biomass. Ants and carabids in croplands follow seasonal reproductive cycles, with overwintering as pupae or adults in soil cavities. These temporal strategies ensure survival across crop rotations and climatic variability.

*B. Physiological adaptations to subterranean life*
Soil insects have evolved multiple physiological traits to endure hypoxic, dark, and humid subterranean conditions (Hoback *et.al.,* 2001). Cuticular modifications, such as reduced pigmentation and wax layers, prevent water loss and enhance mobility through narrow pores. Spiracular control mechanisms allow efficient gas exchange in low-oxygen microenvironments. Specialized mouthparts are adapted to consume decayed plant material or microbial biomass, as observed in Scarabaeidae and Diptera larvae. Enzymatic pathways are fine-tuned for metabolizing recalcitrant compounds such as lignin and cellulose, facilitating decomposition.

*C. Diapause and dormancy mechanisms in soil insects*
Diapause and quiescence are widespread among soil-dwelling insects, serving as survival mechanisms during environmental extremes (Schebeck *et.al.,* 2024).Root maggots (Delia spp.) enter diapause in pupal stages to avoid winter desiccation or heat stress. Collembola and beetle larvae undergo aestivation or prolonged larval diapause under prolonged dry spells. Hormonal regulation, particularly via juvenile hormone and ecdysteroids, governs entry and exit from dormancy states. Soil depth selection during dormancy is strategic, with insects migrating to layers offering thermal buffering and stable moisture conditions.

**V. Role in Nutrient Cycling and Soil Formation**

*A. Litter decomposition and organic matter transformation*
Soil-dwelling insects play a pivotal role in accelerating litter decomposition and transforming organic matter into bioavailable nutrients (Lou *et.al.,* 2022). Decomposer taxa such as termites, isopods, and saprophagous beetles fragment leaf litter and increase surface area for microbial colonization. Termites alone contribute up to 20–30% of organic matter turnover in tropical systems through direct consumption and indirect microbial stimulation. Collembola and dipteran larvae ingest fungal hyphae and decaying plant residues, facilitating nutrient mineralization. These insects act as primary drivers of the detrital food web, ensuring the conversion of complex organic molecules into forms usable by plants.

*B. Influence on microbial communities and enzyme activity*
The activity of soil insects influences microbial diversity, abundance, and spatial distribution (Zhao *et.al.,* 2023). As they consume organic matter, insects modify microbial community structure through selective feeding and gut microbial inoculation. Their fecal pellets provide nutrient-rich microsites that harbour distinct microbial consortia and enhanced enzymatic activities. For instance, termite-modified soils exhibit higher urease, cellulase, and phosphatase activity due to enriched microbial biomass. Carabid beetles and ants have been shown to indirectly enhance microbial respiration and nitrogen mineralization by modifying microhabitats and stimulating root exudation.

*C. Soil bioturbation and aggregate formation*
Bioturbation by insects such as dung beetles, ants, and termites significantly affects soil physical properties and aggregation (Cheik *et.al.,* 2022). Their burrowing and gallery-forming behaviour increases aeration, water infiltration, and redistribution of organic and mineral particles. Termites contribute to microaggregate stabilization by secreting saliva and faecal matter that act as binding agents. Ants transport organic residues into nests, creating nutrient-enriched hotspots and enhancing carbon sequestration in subsoil layers. These processes collectively improve soil structure, porosity, and fertility, promoting sustainable crop production.

**VI. Influence on Crop Health – Beneficial and Detrimental Impacts**

*A. Pest species and root herbivory: crop yield and plant vigour losses*
Several soil-dwelling insects act as major pests by damaging roots, stems, and emerging seedlings (Ambele *et.al.,* 2018). Notable examples include white grubs (Phyllophaga spp.), wireworms (Agriotes spp.), root maggots (Delia spp.), and mole crickets (Gryllotalpa spp.). These insects feed on root systems, reducing water and nutrient uptake and causing stunting or plant death. Wireworm infestation in maize and potato can result in yield losses up to 40%, particularly under minimal tillage regimes. Root herbivory also disrupts root architecture, making crops more susceptible to abiotic stress.

*B. Vectoring of plant pathogens by soil insects*
Certain soil insects serve as vectors of plant pathogens, transmitting fungi, bacteria, and viruses either externally or through feeding. Fungus gnats (Bradysia spp.) are known vectors of *Pythium* and *Fusarium* spp. in greenhouse environments. White grubs have been associated with the transmission of *Phytophthora* and root rot pathogens in fruit trees and legumes (Chandel *et.al.,* 2019). Scarab beetles and ants carry spores of mycorrhizal fungi and plant pathogens across soil layers, altering rhizosphere interactions. Such vectoring exacerbates disease incidence and complicates pest management strategies.

*C. Beneficial insects and plant growth promotion*
Many soil-dwelling insects positively influence plant growth through nutrient provisioning and indirect defence activation. Termites and dung beetles recycle organic nutrients, increasing soil nitrogen and phosphorus availability, which enhances root biomass and crop productivity. Solitary ground-nesting bees (e.g., *Andrena* spp.) contribute to pollination services that enhance fruit set and quality. Carabid beetles suppress root-feeding pest larvae, indirectly supporting healthier plant growth. By improving nutrient access and reducing pest pressure, beneficial soil insects play a synergistic role in promoting agroecosystem health (Altieri *et.al.,* 2003).

*D. Induced systemic resistance and root defence mechanisms*
Root herbivory and insect-associated microbial cues can trigger systemic resistance pathways in plants. Feeding by insects like rootworms and scarabs induces the jasmonic acid pathway, which enhances root lignification and production of secondary metabolites. These responses deter further herbivory and may prime aboveground tissues against foliar pests. Some insects harbour mutualistic microbes that elicit beneficial immune responses in host plants (Grunseich *et.al.,* 2019). Research indicates that rhizosphere exposure to insect frass or exudates can modulate root exudation profiles, fostering beneficial microbial associations. Such mechanisms illustrate the complex interplay between soil insects and plant defence systems.

**VII. Interactions with Other Soil Organisms**

*A. Synergistic and antagonistic interactions with nematodes, fungi, and bacteria*
Soil-dwelling insects interact closely with other soil biota, shaping ecosystem processes through both mutualistic and antagonistic mechanisms (Heinen *et.al.,* 2018). Termites and dung beetles facilitate the proliferation of saprophytic fungi and bacteria by fragmenting litter and depositing nutrient-rich excreta, thereby accelerating microbial colonization. These insects often carry fungal spores and bacterial communities on their cuticle or within their gut, aiding microbial dispersal across heterogeneous soil environments. Conversely, predatory beetles and some ant species exert top-down control on soil nematodes and microbial grazers, thereby modulating microbial abundance and trophic flows. Such interactions influence nutrient turnover, disease suppression, and microbial-driven decomposition.

*B. Role in shaping rhizosphere dynamics*
Soil insects significantly affect rhizosphere structure and function by altering root exudation patterns, microbial community composition, and soil structure (Bonkowski *et.al.,* 2009). Root herbivory by larvae of Scarabaeidae, Elateridae, and Delia spp. induces changes in root secretions, which may favour the recruitment of protective microbes or pathogen suppressive bacteria. Detritivores such as Collembola and isopods modulate microbial biomass and community evenness in the rhizosphere by selectively feeding on fungi and bacteria, influencing competition and nutrient mineralization. Burrowing activities of ants and termites alter root-zone porosity, improving oxygen diffusion and enhancing microbial hotspots that support plant–microbe interactions beneficial to plant health.

*C. Competition, predation, and mutualism in the soil food web*
Insects occupy multiple trophic levels in the soil food web, engaging in diverse interactions that determine ecosystem function (Weisser *et.al.,* 2008). Predatory insects such as carabid beetles feed on root-feeding pests, parasitic nematodes, and larval stages of other insects, contributing to biocontrol. Mutualistic relationships between ants and nitrogen-fixing bacteria or mycorrhizal fungi can enhance nutrient transfer and plant performance. Competition exists among soil-dwelling insects for nesting sites, organic substrates, or prey, particularly in high-density environments. The interplay of these competitive and mutualistic dynamics maintains biodiversity, trophic stability, and functional resilience in soil ecosystems.

**VIII. Soil Management Practices Affecting Insect Communities**

*A. Impact of tillage, irrigation, and mulching*
Soil disturbance through tillage significantly affects the abundance and composition of soil insect communities (Sharley *et.al.,* 2008). Conventional tillage disrupts insect habitats, crushes nests, and exposes subterranean insects to predators and desiccation, leading to declines in populations of beneficial taxa such as carabids, termites, and dung beetles. No-till and reduced tillage systems maintain habitat continuity, enhance organic matter retention, and increase insect richness and activity. Irrigation patterns influence insect movement and survival by altering soil moisture and temperature. Excessive irrigation may drown belowground insects or shift species composition toward more aquatic-tolerant taxa. Mulching promotes favourable microclimatic conditions and protects insects from extreme weather, boosting decomposer and predator diversity while suppressing pests through habitat modification.

*B. Effects of synthetic and organic inputs*
Fertilizers and pesticides impact soil insect biodiversity both directly and indirectly (Altieri *et.al.,* 2012). High nitrogen application favours herbivorous pest insects by increasing plant susceptibility, while reducing the abundance of predators and detritivores sensitive to chemical alterations in soil. Persistent insecticides and fungicides, such as neonicotinoids and chlorpyrifos, have been linked to declines in beetles, ants, and springtails through neurotoxic and endocrine-disruptive pathways. Organic inputs like compost and farmyard manure enhance insect biomass and functional diversity by increasing resource availability and microbial activity. Studies report higher abundance of beneficial insects in organically managed soils compared to conventionally fertilized plots due to lower chemical disturbance and increased habitat complexity.

*C. Crop rotation, intercropping, and conservation agriculture*
Diversified cropping systems positively influence soil insect ecology by enhancing habitat heterogeneity and temporal resource availability (Jaworski *et.al.,* 2023). Crop rotation disrupts pest life cycles and supports generalist predators and parasitoids by alternating host availability. Intercropping creates spatial refuges and alternative food sources, leading to increased insect diversity and functional redundancy. For example, intercropping legumes with cereals increases the abundance of ground beetles and Collembola, promoting pest suppression and nutrient cycling. Conservation agriculture integrates no-till, cover cropping, and minimal chemical use to sustain soil health and insect biodiversity. Long-term studies have demonstrated higher resilience and ecological functioning in insect communities under conservation agriculture compared to conventional systems.

**Table 2:** Soil Management Practices Affecting Insect Communities (Source- Sharley *et.al.,* 2008, Altieri *et.al.,* 2012)

|  |  |  |
| --- | --- | --- |
| **Practice** | **Description** | **Effects on Insect Communities** |
| **Tillage (Conventional/Reduced/Zero)** | Mechanical disturbance of soil | Destroys insect habitats and nests; reduces beneficial insect diversity |
| **Organic Amendments** | Application of compost, manure, or biochar | Enhances detritivore and decomposer populations; improves biodiversity |
| **Cover Cropping** | Growing non-cash crops to cover soil | Provides shelter and food for insects; increases predator populations |
| **Crop Rotation** | Alternating crops seasonally | Interrupts pest life cycles; supports diverse insect communities |
| **Mulching** | Applying plant residues or synthetic cover on soil surface | Moderates soil microclimate; shelters beneficial insects |
| **Irrigation Practices** | Frequency and method of water application | Alters moisture-sensitive insect populations (e.g., springtails, ants) |
| **Chemical Inputs (Pesticides/Fertilizers)** | Use of agrochemicals for crop protection and nutrition | Can harm non-target insects; reduces soil biodiversity |
| **Conservation Agriculture** | Practices like minimum tillage, residue retention, and crop diversity | Promotes stable, diverse, and beneficial soil insect communities |
| **Soil Compaction Management** | Avoidance of heavy machinery, use of controlled traffic farming | Preserves insect burrows and natural soil structure |
| **Agroforestry and Perennial Systems** | Integration of trees or long-term crops | Enhances habitat complexity; supports higher insect diversity |

**IX. Ecological Indicators and Bioindication Potential**

*A. Use of soil insects as indicators of soil health and disturbance*
Soil-dwelling insects respond predictably to ecological disturbances, making them valuable indicators of soil quality, biodiversity loss, and land degradation (Menta *et.al.,* 2020). Species such as Carabidae (ground beetles), Formicidae (ants), and Collembola (springtails) have been extensively studied for their sensitivity to environmental changes. High diversity and abundance of predator insects typically indicate biologically active and structurally stable soils, whereas a dominance of opportunistic taxa may signal soil degradation or pollution. Functional group analysis helps infer the status of nutrient cycling, organic matter decomposition, and biological control processes, positioning soil insects as essential bioindicators of agroecosystem resilience.

*B. Bioassessment protocols and sampling methodologies*
Standardized protocols for insect-based bioassessment involve pitfall trapping, Berlese funnel extraction, and soil monolith sampling. Pitfall traps are widely used for capturing surface-active taxa such as carabids and ants and are effective for long-term monitoring (Yi *et.al.,* 2012). Litter extraction using Tullgren or Berlese funnels helps recover smaller arthropods like Collembola and mites. Quantitative parameters including species richness, Shannon diversity index, and trophic structure are analysed to assess disturbance intensity. Recent advances include DNA metabarcoding to identify cryptic species and functional traits at high resolution, improving the reliability of insect-based soil health evaluations.

*C. Case studies on bioindication in agricultural landscapes*
Multiple field studies have demonstrated the utility of soil insects in monitoring agroecosystem dynamics (Alyokhin *et.al.,* 2020). A study showed that ant species richness and functional diversity significantly decreased under intensive monoculture systems compared to diversified organic farms. In Brazilian agroforestry systems, dung beetle diversity correlated positively with soil carbon content and negatively with pesticide load. Research in European cereal fields found reduced carabid activity and biomass under conventional tillage, highlighting their sensitivity to soil compaction and chemical exposure. These cases validate the potential of soil insect communities as proxies for soil ecological quality and landscape sustainability.

**X. Climate Change and Anthropogenic Influences**

*A. Changes in soil temperature, moisture, and organic matter*
Climate-driven changes in soil temperature and moisture directly affect the physiology, survival, and distribution of soil-dwelling insects (Sharma *et.al.,* 2023). Increased soil temperatures accelerate metabolic rates, potentially leading to higher reproductive turnover but reduced lifespan in taxa such as Collembola and beetle larvae. Moisture deficits reduce insect mobility and microbial interactions, impairing decomposition and nutrient cycling processes. Experimental warming studies have shown a decline in decomposer insects under drought-prone conditions, with significant consequences for organic matter stabilization. Shifts in litter input and microbial composition due to altered precipitation patterns influence habitat quality for insects, particularly those involved in detrital pathways.

*B. Habitat loss and fragmentation*
Agricultural intensification, deforestation, and land-use conversion contribute to the fragmentation of soil insect habitats, disrupting trophic interactions and spatial dispersal (John *et.al.,* 2022). Habitat loss reduces genetic diversity and leads to local extinction of sensitive taxa such as stenotopic carabids and forest-dwelling ants. Fragmentation impedes recolonization, especially for soil-nesting pollinators and predators dependent on specific microhabitats. Studies indicate that landscape connectivity influences the abundance of functionally important insects like dung beetles and termites, which play a key role in nutrient recycling and soil aeration. Maintaining habitat corridors and diversified field margins can buffer against these negative impacts.

*C. Invasive soil insect species and range shifts*
Anthropogenic movement of soil and climate anomalies have facilitated the global spread of invasive soil insects, often disrupting native communities and soil processes (Meyer et.al., 2021). The spread of *Solenopsis invicta* (red imported fire ant) in Asia and parts of Africa has led to altered predation dynamics and reduced diversity of endemic ants and beetles. Climate-induced range shifts are altering the distribution boundaries of root herbivores such as wireworms and rootworms, which now threaten new cropping zones. Model projections suggest that global warming may enable tropical insect species to colonize temperate soils, potentially leading to ecological imbalances and novel pest outbreaks (Subedi *et.al.,* 2023). Management of invasive and range-expanding soil insects requires integration of surveillance tools, habitat restoration, and ecological forecasting.

**XI. Approaches to Enhance Soil Insect-Mediated Crop Health**

*A. Agroecological approaches for beneficial insect conservation*
Agroecology emphasizes ecosystem-based practices that promote biodiversity and ecological balance (Duru *et.al.,* 2015). Conservation tillage and organic farming are recognized for their positive impact on soil insect populations by preserving habitat structure and minimizing chemical disturbance. Cover cropping increases detrital inputs and soil moisture, supporting detritivores like Collembola and Diplopoda, which contribute to organic matter breakdown and nutrient mineralization. Use of native plant species in field margins encourages colonization by predatory and mutualistic insects such as ants and carabid beetles, which suppress belowground pests and improve soil health. Agroforestry systems offer vertical stratification and continuous organic inputs, creating ideal conditions for soil insect diversity and functional resilience.

*B. Use of insect-based biofertilizers and biocontrol agents*
Soil insects contribute directly to nutrient enrichment through excreta and indirect stimulation of microbial nutrient cycling (Hartley *et.al.,* 2008). Dung beetles, for example, bury organic matter and enhance nitrogen availability to root zones, increasing crop uptake efficiency. Termite activity has been associated with phosphorus mobilization and increased soil porosity in dryland systems. Insect-derived frass and composted insect biomass have emerged as novel biofertilizer sources due to their rich nitrogen and micronutrient content. Predators like rove beetles and parasitic wasps have been utilized in augmentative biocontrol programs to manage pests such as root maggots and soil-borne larvae, contributing to integrated pest management strategies.

*C. Habitat manipulation and ecological engineering strategies*
Deliberate modification of the agroecosystem structure can enhance the abundance and activity of soil insects (Hartmann *et.al.,* 2023). Practices such as planting trap crops or flowering strips enhance the presence of beneficial insects by supplying nectar and alternative prey, stabilizing pest suppression services. Mulching with organic residues improves microhabitat stability, moisture retention, and detritivore populations that facilitate nutrient turnover. Soil ridging and creation of microrefuges using straw bundles or root logs support overwintering of predatory beetles and ants. Engineering soil environments by introducing decomposable substrates like compost or vermicast can stimulate insect-mediated decomposition and microbial symbioses, optimizing belowground plant support systems.

**XII. Research Gaps and Future**

*A. Need for long-term and multi-scalar ecological studies*
Despite the well-documented role of soil insects in ecosystem processes, most studies remain short-term or plot-specific (Scherr *et.al.,* 2008). There is an urgent need for long-term ecological research that captures seasonal, interannual, and successional changes in soil insect communities and their ecosystem functions. Multi-scalar studies that integrate microhabitat, field, and landscape-level observations are essential to understand how soil insects respond to land-use gradients, climate variability, and crop intensification. Such studies will provide reliable data for modelling insect-mediated nutrient cycling, pest control, and carbon sequestration under future agricultural scenarios.

*B. Integrating soil entomology with crop management*
Soil insect ecology is underrepresented in crop management models and decision-support systems (Roche *et.al.,* 2023). There is a gap in linking entomological data with agronomic variables such as yield stability, fertilizer use efficiency, and root health. Integrating soil insect indicators into frameworks like conservation agriculture, precision farming, and climate-smart agriculture can enhance system resilience and sustainability. Development of management thresholds for beneficial and pest soil insects is critical for informed interventions. Training extension personnel and farmers in soil entomology and insect-based diagnostics will aid practical application of biodiversity-enhancing strategies.

*C. Advances in molecular tools and soil metagenomics*
Recent breakthroughs in high-throughput sequencing, DNA barcoding, and environmental DNA (eDNA) offer new avenues for exploring soil insect diversity and function (Kestel *et.al.,* 2022). Metagenomic approaches enable identification of cryptic taxa and gut microbial communities that mediate ecological functions like cellulose degradation and nitrogen fixation. Transcriptomic analyses can reveal stress responses, trophic roles, and interaction networks among soil insects and microorganisms. Incorporating molecular tools into soil biodiversity monitoring programs will enhance accuracy, resolution, and functional interpretation, bridging the gap between taxonomy and ecosystem function.

**XIII. Conclusion**

Soil-dwelling insects serve as critical agents in agroecosystems, influencing nutrient cycling, soil structure, microbial dynamics, and plant health through complex ecological interactions (Neher *et.al.,* 2019). Their roles as decomposers, predators, herbivores, and bioindicators reflect their functional diversity and sensitivity to environmental change. Conservation-oriented management practices such as reduced tillage, organic amendments, cover cropping, and habitat diversification enhance insect-mediated services while mitigating pest pressures. Climate variability, habitat fragmentation, and chemical inputs pose significant threats to their biodiversity and ecosystem contributions (Segan *et.al.,* 2016). Integrating soil entomology into crop management, advancing bioassessment tools, and leveraging molecular technologies will strengthen our capacity to sustain productive and resilient agricultural systems. Long-term, multi-scale research is essential to fully elucidate the ecological significance of soil insects and to design evidence-based strategies that harness their potential in promoting soil health, biodiversity, and sustainable food production under changing environmental conditions.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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