SUNSHINE AGRICULTURE
e-Newsletter

ISSN (E): 2583 – 0821

Sun. Agri.:e- Newsletter, (2026) *6*(7), 85-88

Article ID: 632

Impact of Climate Change on Insect Pest Distribution

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Available online at
www.sunshineagriculture.vitalbiotech.org

Article History
Received: 14.07.2026
Revised: 19.07.2026
Accepted: 24.07.2026

INTRODUCTION

Climate change, driven largely by anthropogenic greenhouse gas emissions, is steadily raising global mean temperatures, shifting rainfall patterns, and increasing the frequency of heatwaves, droughts, and floods. Among the many biological systems affected, insects respond with unusual speed because they are ectotherms whose metabolism, growth, and reproduction are governed directly by ambient temperature and moisture. Even modest warming can shorten generation times, expand breeding cycles per year (voltinism), and permit survival through winters that were previously lethal.

Four climatic drivers dominate insect responses: temperature, which governs development rate and overwintering survival; rainfall, which shapes breeding habitat and host-plant availability; humidity, which influences moulting and disease susceptibility; and rising carbon dioxide, which alters plant chemistry and, indirectly, pest nutrition. Extreme weather events add further volatility, triggering sudden outbreaks such as desert locust plagues following anomalous rainfall.

Because agriculture depends on a delicate synchrony between crop phenology, pest life cycles, and natural enemies, even small climatic disruptions can translate into large yield losses. With the world's population expanding and arable land shrinking, understanding how climate change reshapes insect pest distribution is central to safeguarding global food security.

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1. How Climate Change Influences Insect Biology

Temperature is the single most influential abiotic factor governing insect physiology. Within a species' thermal optimum, warming accelerates larval and nymphal development and shortens generation time, but beyond that optimum it induces heat stress and mortality (Battisti & Larsson, 2015). This dual effect explains why the same warming trend can expand a pest's range at higher latitudes while contracting it near the equator, as demonstrated for the fall armyworm, whose invasive range in Africa is projected to retract from hot northern and southern fringes toward cooler equatorial zones even as it advances elsewhere (Paudel Timilsena et al., 2022).

Rainfall and humidity regulate breeding habitat quality, egg survival, and disease pressure among insect populations. Desert locusts remain confined to arid recession areas until anomalous, above-average rains create the green vegetation corridors needed for mass breeding and gregarisation (Kimathi et al., 2020; Salih et al., 2020). Elevated carbon dioxide subtly alters plant nitrogen and secondary metabolite concentrations, often forcing herbivorous insects to consume more foliage to meet nutritional needs, increasing crop damage even without a change in pest numbers.

Voltinism, migration, and diapause are all sensitive to these variables. Warmer winters permit additional generations per season and expand overwintering ranges; the diamondback moth's global overwintering range has already expanded by roughly 2.4 million square kilometres over five decades in step with warming (Fu et al., 2021). Long-distance migrants such as the brown planthopper are similarly expected to establish new overwintering zones in mid-latitude regions as heat stress reduces suitability near the equator (Otuka et al., 2024).

2. Changes in Insect Pest Distribution

The clearest ecological signature of climate change on insects is range shift. Poleward movement has been documented across taxa, from the classic case of European butterflies expanding northward with regional warming (Parmesan et al., 1999) to contemporary agricultural pests. Altitudinal expansion is equally well established: alpine and montane insects are increasingly recorded at higher elevations as lowland habitats warm beyond their thermal tolerance, often accompanied by range contraction at mountain summits.

Seasonal changes are also striking. Nearly five decades of aphid suction-trap data in the United Kingdom show that all fifty-five monitored species, including major cereal pests, now take flight earlier in the year, a trend linked to greater crop injury and virus transmission (Bell et al., 2015; Hemming et al., 2022). In North America, the spruce budworm has shown a pronounced northward expansion of climatically suitable habitat alongside earlier phenology since the mid-twentieth century (Bourassa et al., 2025). In Asia, new overwintering boundaries for the brown planthopper are projected to expand into central and eastern China and southern Australia. Across India and South Asia, warmer, more humid conditions are extending the active season of whiteflies and aphids, intensifying virus transmission in pulses, cotton, and vegetable crops. New pest establishment beyond historical ranges, seen in the fall armyworm's spread from the Americas to Africa, Asia, and Oceania within less than a decade, illustrates how climate suitability can outpace natural biogeographic barriers when combined with global trade.

3. Emerging and Invasive Insect Pests

Several species exemplify climate-facilitated invasion. The fall armyworm (*Spodoptera frugiperda*), native to the Americas, reached Africa in 2016 and had spread to more than one hundred countries within a few years, aided by its wide host range, strong flight capacity, and tolerance of warm climates (Paudel Timilsena et al., 2022; Rwomushana et al., 2018). The desert locust (*Schistocerca gregaria*) produced its worst outbreak in twenty-five years across East Africa and South-West Asia during 2019–2021, tied to unusually heavy, climate-linked rainfall from the Indian Ocean Dipole (Salih et al., 2020). The brown planthopper (*Nilaparvata lugens*), a major rice pest, is projected to expand its overwintering range poleward under future warming scenarios (Otuka et al., 2024). Mustard aphid (*Lipaphis erysimi*) populations in South Asia respond strongly to winter temperature anomalies, with warmer winters permitting earlier, more damaging infestations of oilseed brassicas. The whitefly (*Bemisia tabaci*) species complex, already among the world's most invasive pests, is expected to expand further into temperate Europe under simulated future climates (Macfadyen & Paull, 2023), while in India it continues to intensify transmission of yellow mosaic and leaf-curl viruses under warmer, sunnier conditions (Skendžić et al., 2021). Fruit flies (*Bactrocera* spp.) are similarly extending seasonal activity windows across South and Southeast Asia.

4. Impacts on Agriculture

The agronomic consequences of these shifts are substantial. Expanding pest ranges and longer breeding seasons increase the frequency and severity of outbreaks, directly reducing crop productivity in staples such as maize, rice, and oilseeds. Farmers commonly respond by intensifying pesticide use, which raises production costs, accelerates insecticide resistance, and erodes already thin farm incomes, particularly among smallholders in Sub-Saharan Africa and South Asia (Skendžić et al., 2021). These pressures cascade into food security concerns, since staple grain losses of even ten to twenty per cent can be catastrophic in subsistence systems. Climate change also affects biodiversity underpinning natural pest suppression: shifts in pollinator timing can desynchronize plant–pollinator interactions, while heat and moisture stress on parasitoids and predatory insects weakens biological control services farmers rely upon.

5. Climate-Smart Pest Management

Meeting these challenges requires an integrated, technology-enabled approach. Integrated Pest Management (IPM) remains the foundation, combining cultural, biological, and chemical tactics to minimise reliance on any single control method. Pest forecasting models, such as CLIMEX-based projections used for the fall armyworm and brown planthopper, allow early identification of at-risk regions before outbreaks occur (Paudel Timilsena et al., 2022). Artificial intelligence is increasingly embedded in these systems, enabling automated pest identification from images, population forecasting, and site-specific decision support (Aziz et al., 2025). Remote sensing and drone-based surveillance extend monitoring across large landscapes, detecting vegetation stress and locust breeding habitats from satellite and aerial imagery (Landmann et al., 2023). Complementary strategies include breeding pest-resistant varieties, conserving natural enemies for biological control, adopting conservation agriculture, and deploying digital advisories to farmers' phones, together enabling more precise, sustainable pest management.

6. Future Research Priorities

Building genuine climate resilience in pest management will depend on several priorities. Predictive modelling must move beyond single-species projections toward multi-trophic frameworks capturing interactions among pests, crops, and natural enemies under future climates. Genomic tools can help identify adaptive traits enabling rapid range expansion and resistance evolution in pests such as *Bemisia tabaci* and *Spodoptera frugiperda*. Artificial intelligence and decision-support systems should be scaled from research prototypes to accessible tools for extension workers and smallholders. Finally, because pest ranges cross borders, sustained international collaboration and coordinated early-warning networks—along the lines already operating for desert locust monitoring—will be essential for anticipating future outbreaks.

ISSN (E): 2583 – 0821

CONCLUSION

Climate change is fundamentally altering where, when, and how severely insect pests affect agriculture. Rising temperatures, shifting rainfall, elevated carbon dioxide, and extreme weather events are jointly reshaping insect development, reproduction, and migration, producing poleward and altitudinal range shifts, earlier seasonal emergence, and the establishment of invasive species such as the fall armyworm and desert locust far beyond their historical ranges. These changes threaten crop productivity, elevate pesticide dependence, strain farmer livelihoods, and disrupt the biodiversity that supports natural pest regulation and pollination. Meeting this challenge demands climate-smart pest management that integrates traditional IPM principles with modern tools—predictive modelling, artificial intelligence, remote sensing, resistant varieties, and biological control—delivered through accessible digital platforms. Sustained investment in research, genomics, and international collaboration will be essential to anticipate emerging threats before they escalate. Ultimately, safeguarding global food security in a warming world requires treating insect pest management not as a static practice but as an adaptive, science-driven response to a rapidly shifting climate.