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Climate Change and Agricultural Insect Pests: Impacts on Distribution, Population Dynamics and Crop Losses

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Climate change is altering the ecological conditions under which agricultural insect pests survive, reproduce, disperse and interact with crops and natural enemies. Rising temperatures, altered rainfall, elevated atmospheric carbon dioxide and more frequent extreme weather events can modify pest development rates, overwintering survival, seasonal occurrence, geographic distribution and the number of generations completed within a crop season. Warming is also allowing several pests to expand into higher latitudes and elevations, while altered precipitation and land-use patterns can create new opportunities for establishment and outbreaks. These changes have direct consequences for crop protection because pest populations may appear earlier, remain active for longer periods or reach damaging densities at different crop growth stages. Recent syntheses indicate that warming can increase pest-related yield losses in major cereals, although responses differ among pest species, crops and climatic regions. In India, climate-based species distribution and phenology models are increasingly being used to assess future risks, including projections for rice thrips, brown planthopper and pink bollworm. This review summarizes the major climate drivers affecting agricultural insect pests, examines their impacts on distribution and population dynamics, discusses consequences for crop losses, and outlines climate-smart approaches involving surveillance, forecasting, resistant cultivars, biological control, cultural practices and integrated pest management. Strengthening pest monitoring and linking climatic information with early-warning systems will be essential for resilient and sustainable crop production.

Introduction

Agricultural insect pests are among the most persistent biological constraints to crop production and food security. Insects damage crops directly through feeding on leaves, stems, roots, flowers, fruits and seeds, and indirectly through transmission of plant pathogens. The magnitude and timing of pest damage are strongly influenced by environmental conditions, particularly temperature, rainfall, humidity and seasonal weather patterns. Climate change is therefore not simply an additional stress on agriculture; it is modifying the ecological context in which pest outbreaks develop. Reviews of agricultural entomology have shown that climate change can alter pest geographic distribution, overwintering survival, development, voltinism, host synchrony, species interactions and the effectiveness of natural enemies (Skendžić *et al.*, 2021). The importance of this issue is increasing because agricultural systems are already experiencing substantial losses from pests. The Food and Agriculture Organization has reported that up to 40% of global crop production can be lost to pests, while invasive insects account for a major share of the associated economic burden (FAO, 2021). Climate change may intensify these losses in some regions by making previously unsuitable environments favourable for pest establishment or by increasing the rate at which populations develop. However, responses are not uniform. Excessive heat can reduce survival of some insects, and extreme rainfall or drought can suppress particular species. Consequently, the outcome depends on the interaction among pest thermal limits, crop phenology, natural enemies, landscape characteristics and agricultural management. Recent global syntheses have emphasized that crop pests are generally responding to warming through expanded geographic ranges, earlier phenological events and, in suitable environments, an increased number of reproductive generations per year (Ma *et al.*, 2025). Such responses are especially important in temperate and mid-to-high latitude production systems, where warming can move temperatures closer to the optimum for pest development. The consequences for tropical agriculture can be more complex because many pests already experience relatively warm conditions and may approach upper thermal limits. This review therefore focuses on the mechanisms by which climate change affects pest distribution and population dynamics and how these changes translate into crop losses and management challenges.

Climate Drivers Affecting Agricultural Insect Pests

Temperature is the most important climatic factor controlling the rate of insect development because insects are ectothermic organisms. Within a species-specific thermal range, increasing temperature generally accelerates egg, larval, nymphal and pupal development, shortens generation time and can increase the number of generations completed during a growing season. At temperatures above the optimum, however, survival, fecundity and development may decline sharply. Therefore, the relationship between warming and pest abundance is frequently nonlinear rather than a simple increase with temperature (Skendžić *et al.*, 2021). Changes in rainfall and humidity can also modify pest abundance. Moderate water stress may increase the susceptibility of crops to herbivory, while drought can alter plant chemistry and reduce the effectiveness of natural enemies. In contrast, heavy rainfall can physically remove small-bodied insects from plants, but prolonged humid conditions may favour some pests and their host plants. Recent global synthesis indicates that precipitation responses differ among pest groups, with the effect depending on pest size, feeding behaviour, life stage and environmental context (Ma *et al.*, 2025). Elevated atmospheric CO2 affects insect pests mainly through changes in their host plants. Increased CO2 can alter plant carbon-to-nitrogen ratios, secondary metabolites and tissue quality, which may change herbivore feeding, growth and reproduction. The direction and magnitude of these responses are variable, and the effects of CO2 cannot be separated from simultaneous changes in temperature and water availability. Tonnang *et al.* (2022) emphasized that improved crop–pest models should incorporate two-way feedbacks because pest injury changes crop growth while climate and crop condition simultaneously influence pest populations. Extreme events such as heat waves, unseasonal rainfall, floods, droughts and unusually mild winters can create abrupt changes in pest populations. A mild winter may increase overwintering survival and permit earlier colonization, whereas a severe heat event may exceed the upper thermal limit of a pest. Such events can also disrupt natural enemies, producing temporary release of pest populations. Consequently, climate variability can be as important as long-term mean warming when assessing outbreak risk.

Impacts on Geographic Distribution and Range Expansion

One of the clearest consequences of climate change is the movement of suitable climatic habitats. As temperatures increase, some agricultural pests can establish farther northward, southward or at higher elevations where winters were previously limiting. Range expansion is particularly important for invasive and migratory pests because establishment in a new region may occur before farmers and extension services have adequate surveillance or management protocols. FAO has highlighted that climate change increases the risk of pest spread, particularly in cooler Arctic, boreal, temperate and subtropical regions, where warmer conditions can facilitate establishment of organisms that previously failed to survive (FAO, 2021). Range expansion is not necessarily accompanied by a uniform increase in abundance. A pest may expand geographically but remain restricted to locations where host availability, humidity and seasonal temperature are suitable. Conversely, warming may cause range contraction in areas that become excessively hot or dry. The net distribution therefore represents the balance between thermal suitability, moisture, crop distribution, landscape connectivity and biological interactions. Recent global evidence indicates that mid- and high-latitude pests often respond more positively to warming than tropical pests because many temperate environments remain below the thermal optimum for development (Ma *et al.*, 2025). Climate-driven range changes are already being assessed with ecological niche and species distribution models. In India, Pushpalatha *et al.* (2024) used MaxEnt and future climate scenarios to project the distribution of rice thrips, Stenchaetothrips biformis. Their projections identified substantial future suitability in southern and northeastern India and showed that temperature-related variables were important predictors. Such studies are valuable because they can identify districts or production zones that may require intensified surveillance before pest pressure becomes severe.

Effects on Population Dynamics, Phenology and Voltinism

Population dynamics describe changes in pest abundance through time and are controlled by birth, death, immigration and emigration. Climate change can influence all four processes. Warmer conditions within the favourable thermal range may increase development and reproduction, while milder winters can improve survival of overwintering stages. Earlier spring warming can cause adults or nymphs to appear before their traditional monitoring dates, creating a mismatch between pest occurrence and existing scouting schedules. Phenology is especially important because crop injury depends not only on pest abundance but also on whether the susceptible crop stage overlaps with the damaging life stage of the insect. Climate-driven advancement of pest development can shift the timing of egg laying, larval feeding and adult migration. If crop development does not shift at the same rate, synchrony may increase and damage may become more severe. Alternatively, altered synchrony can sometimes reduce pest success. Thus, pest phenology should be interpreted together with crop phenology rather than as an independent response. An additional concern is voltinism, or the number of generations completed in a year. A warmer growing season can permit an additional generation in regions where temperature previously limited development. More generations can increase cumulative feeding damage and provide more opportunities for migration and reproduction. Global assessments have identified increased reproductive generations as a common response of crop pests to warming, although the effect is species- and region-specific (Ma *et al.*, 2025).

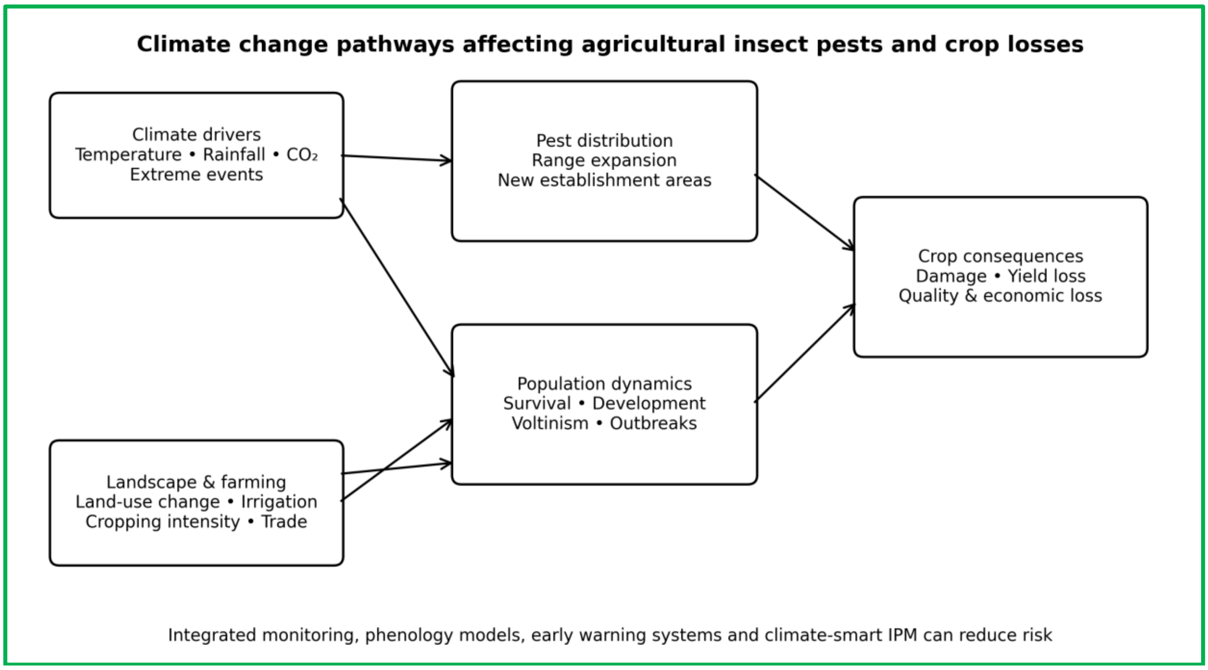

Figure 1. Climate-driven pathways affecting agricultural insect pest distribution, population dynamics and crop losses, with major opportunities for climate-smart pest management.

Temperature-driven phenology models are therefore becoming important tools for pest risk assessment. In India, recent work on pink bollworm, Pectinophora gossypiella, combined a temperature-driven phenology model with field damage observations to estimate current and future cotton yield losses. The study projected expansion of areas experiencing more than six annual generations under climate-change scenarios, while also showing that excessively high temperatures can reduce pest survival and reproduction in some regions (Fand *et al.*, 2025). This illustrates why climate impacts should be evaluated using species-specific thermal responses rather than assuming that all pests increase continuously with warming.

Altered Pest–Crop–Natural Enemy Interactions

Climate change affects insect pests within a multitrophic system rather than in isolation. Herbivorous insects interact with host plants, predators, parasitoids, pathogens and competing herbivores. A temperature increase that benefits a pest may not benefit its parasitoid or predator to the same extent. Differences in thermal thresholds can therefore weaken biological control if pests develop faster than their natural enemies. Conversely, some natural enemies may respond positively to warming and partially offset pest increases. The final outcome depends on the relative sensitivity and timing of all interacting organisms (Heeb *et al.*, 2019; Skendžić *et al.*, 2021). Changes in crop management can amplify these effects. Irrigation may maintain host-plant quality during dry periods, while fertilization can increase plant biomass and alter tissue nutritional quality. Simplified landscapes and loss of non-crop habitats may reduce refuges and alternative resources for natural enemies. The 2025 synthesis by Ma *et al.* emphasized that climate change interacts with land-use change and agricultural intensification, making pest responses difficult to attribute to climate alone. This reinforces the need for landscape-scale rather than single-field pest management. Climate change can also influence pesticide performance and resistance evolution indirectly. Changes in pest population growth, exposure frequency and seasonal timing may increase pesticide applications when farmers attempt to compensate for unpredictable outbreaks. Repeated or poorly timed applications can intensify selection pressure for resistance and may further disrupt beneficial insects. Climate-smart integrated pest management should therefore prioritize monitoring, thresholds, biological control and targeted interventions instead of routine calendar-based spraying (Heeb *et al.*, 2019).

Climate Change and Crop Losses

Crop loss caused by insect pests results from the interaction between pest abundance, feeding rate, crop susceptibility and the timing of injury. Warming can increase both pest population growth and individual metabolic demand for food, potentially increasing crop consumption. Deutsch *et al.* (2018) estimated that yield losses of wheat, rice and maize attributable to insect pests could increase by approximately 10–25% for each degree Celsius of global mean warming, with particularly strong effects in temperate production regions. These projections demonstrate that insect-mediated losses can add to the direct effects of heat and water stress on crops.

More recent synthesis has refined the picture by incorporating climate, land use and agricultural practices. Under 2 °C warming, pest-related damage was projected to exacerbate yield losses by 46% for wheat, 19% for rice and 31% for maize, although the magnitude varies among regions and pest groups (Ma *et al.*, 2025). These values should be interpreted as model-based projections rather than universal field losses. Actual outcomes will depend on crop variety, pest species, management, natural enemies, irrigation and local weather.

India provides examples of how pest risk can be linked with climate scenarios. For rice, future distribution modelling of rice thrips indicates expansion of climatically suitable areas under multiple emissions pathways (Pushpalatha *et al.*, 2024). For cotton, Fand *et al.* (2025) demonstrated the value of integrating phenology and field damage data to quantify pink bollworm losses. These studies show that national and regional crop-loss assessments can be strengthened by combining historical pest observations with weather data, crop calendars and mechanistic or statistical models.

Crop losses are not limited to yield quantity. Pest feeding can reduce quality, marketability, seed viability, fibre quality and post-harvest value. Fruit and vegetable pests can cause direct cosmetic damage that leads to rejection even when total biomass loss is relatively small. In stored products, temperature-dependent insect development can accelerate deterioration and contamination. Climate change may therefore increase both pre-harvest and post-harvest pest risks, requiring coordinated surveillance across the entire crop value chain.

Examples of Climate-Related Pest Risks in Major Crops

Rice: Rice systems are exposed to several climate-sensitive pests, including planthoppers, stem borers, leaf folders and thrips. Changes in temperature, rainfall and humidity can alter pest abundance and migration. A recent CMIP6-based study of brown planthopper, Nilaparvata lugens, in India found that temperature-related variables accounted for a large share of habitat suitability and used future climate scenarios to map potential changes for 2050 and 2070 (Sahoo *et al.*, 2026). Such projections can help prioritize surveillance and strengthen early warning in vulnerable rice-growing regions.

Wheat and maize: These cereals are particularly important in global food security and have been central to modelling studies of climate-related insect damage. Warming can increase pest pressure in regions where temperatures move toward insect optima, while drought can modify crop susceptibility and plant–insect interactions. The projected increase in insect-mediated yield losses for wheat and maize under warming highlights the importance of incorporating pest dynamics into crop-climate impact assessments rather than modelling crop yield alone (Deutsch *et al.*, 2018; Ma *et al.*, 2025).

Cotton: Cotton pest complexes include bollworms, sucking pests and other insects whose population dynamics are strongly influenced by temperature and crop phenology. Recent Indian research on pink bollworm illustrates the importance of temperature-driven generation estimates and field-based loss assessment. The study reported that more than six generations currently occur across a substantial proportion of cotton-growing areas and projected an increase in the proportion of areas reaching this generation frequency by 2050, although very high temperatures may suppress pest survival in some locations (Fand *et al.*, 2025).

Vegetables and horticultural crops: Vegetable and fruit crops can be affected by aphids, whiteflies, thrips, fruit flies, leaf miners, caterpillars and mites. Because these crops often have high economic value and relatively short production cycles, a small change in pest timing can have a disproportionate economic effect. Warmer conditions can also increase the number of pest generations during protected cultivation, making greenhouse monitoring and climate control increasingly important.

Monitoring, Forecasting and Risk Mapping

Traditional pest monitoring remains essential, but climate change requires monitoring systems that are more continuous and predictive. Pheromone traps, sticky traps, light traps, field scouting and crop damage assessments can provide observations of pest abundance. These observations become more useful when linked with weather stations, remote sensing, geographic information systems and crop calendars. Long-term datasets can reveal changes in pest phenology and range that are difficult to detect from isolated outbreak reports. Forecasting systems can use degree-day accumulation, temperature-dependent development rates, population models and species distribution models to estimate when and where pest risk is likely to increase. MaxEnt and related ecological niche approaches are useful for mapping potential distribution, while mechanistic phenology models can estimate development and generation number. Tonnang *et al.* (2022) emphasized that crop and pest models should ideally be coupled so that pest injury affects crop growth and crop condition feeds back to pest development. Early-warning systems should communicate risk at a scale that farmers can use. A district-level warning may be useful for extension planning, whereas field-level alerts can support targeted interventions. Digital platforms, automated traps and remote sensing can strengthen this process, but they should complement rather than replace field validation. Model uncertainty, limited pest occurrence data and rapidly changing climate conditions must be communicated clearly to avoid false confidence.

Climate-Smart Pest Management and Adaptation

Climate-smart pest management aims to reduce pest-induced crop losses while improving the resilience and environmental sustainability of production systems. Heeb *et al.* (2019) proposed a coordinated approach in which farm management, landscape design, research, extension and policy are aligned to address changing pest threats. This approach is compatible with integrated pest management and emphasizes prevention, monitoring and ecological regulation. First, surveillance should be strengthened through regular scouting, pheromone and sticky traps, weather-linked monitoring and digital reporting. Second, pest thresholds should be updated where climate change shifts pest development or crop susceptibility. Historical economic thresholds may not remain appropriate if pests appear earlier or complete additional generations. Third, resistant or tolerant crop varieties should be incorporated wherever suitable. Breeding programs can consider both current pest populations and projected future pest distributions. Biological control is another important adaptation strategy. Conserving predators, parasitoids and entomopathogenic organisms can provide background suppression and reduce reliance on broad-spectrum insecticides. Maintaining flowering resources, field margins and semi-natural habitats may improve natural-enemy persistence. However, biological control agents themselves are climate-sensitive, so their thermal and moisture requirements should be considered when designing future IPM programs. Cultural practices can also reduce climate-related pest risk. Adjusting sowing dates, using short-duration cultivars where appropriate, synchronized planting, crop rotation, removal of crop residues that harbour pests, weed management and balanced irrigation can reduce opportunities for pest establishment. At the landscape level, diversification and habitat management can improve ecological stability. Chemical control remains an important component of IPM when economic thresholds are exceeded, but applications should be targeted, selective and timed according to pest stage and weather conditions. Finally, climate-smart pest management should incorporate forecasting and scenario planning. Farmers and extension personnel can use seasonal climate forecasts and pest models to anticipate high-risk periods. National plant protection organizations can combine surveillance data with climate and trade information to improve biosecurity and invasive-pest preparedness. These measures are particularly important because climate change can alter the geographic boundaries within which pest quarantine assumptions were developed.

Research Gaps and Future Directions

Despite rapid progress, several uncertainties remain. Many pest models are based on laboratory thermal responses that may not fully represent field conditions. Interactions among temperature, humidity, plant nutrition, natural enemies and management are difficult to reproduce experimentally. More long-term field datasets are required to validate predictions across contrasting agroecological zones. Future research should prioritize species-specific thermal performance curves, pest–crop–natural enemy models, standardized field surveillance and integration of pest occurrence records with high-resolution climate data. Artificial intelligence and machine learning can assist with risk mapping and outbreak prediction when adequate training data are available, but models should be validated across locations and years. Explainable and uncertainty-aware modelling will be especially important for decisions involving pesticide use and crop protection. Another major research need is the integration of climate change with pest resistance and invasive-species risk. Warmer climates may change the timing and intensity of insecticide exposure, while expanded pest ranges may introduce populations with different resistance profiles. Future crop protection strategies should therefore connect climate forecasting, resistance monitoring, biological control and border surveillance. Participatory approaches involving farmers, extension workers and researchers can improve the relevance of these systems at field level.

Conclusion

Climate change is reshaping agricultural entomology by modifying where insect pests can survive, when they appear, how rapidly they reproduce and how much damage they can cause. Rising temperature, changing rainfall, elevated CO2, extreme events, land-use change and agricultural intensification interact to determine pest distribution and population dynamics. The strongest responses are expected where climatic conditions move toward the physiological optimum of individual pest species, while excessive heat can suppress populations beyond their upper thermal limits. Consequently, climate impacts must be assessed using species- and region-specific evidence. Current evidence indicates that climate-driven changes in pest distribution, phenology and voltinism can increase crop protection risks and may amplify yield losses in major crops. Indian studies on rice thrips, brown planthopper and pink bollworm demonstrate the practical value of climate-based distribution and phenology modelling. The future of pest management should therefore move from reactive control toward continuous surveillance, forecasting, climate-resilient crop production and integrated pest management. Combining farmer knowledge with weather data, field monitoring, biological control, resistant varieties and decision-support models will be essential to maintain crop productivity and reduce the environmental costs of pest management under a changing climate.

References

1. Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B. and Naylor, R.L. (2018). Increase in crop losses to insect pests in a warming climate. *Science*, 361(6405): 916–919. https://doi.org/10.1126/science.aat3466
2. Fand, B.B., Shah, V., Nagrale, D.T., Mahule, D.J., Gawande, S.P., Thube, S.H., Pandiyan, K., Ramteke, I., Kumar, R., Rameash, K., Prabhulinga, T., Nagrare, V.S., Behere, G.T. and Prasad, Y.G. (2025). Field estimates of current and predicted cotton yield loss due to pink bollworm and boll rot in India. *Agricultural Systems*, 224: 104246. https://doi.org/10.1016/j.agsy.2024.104246
3. FAO (2021). Climate change fans spread of pests and threatens plants and crops: New FAO study. Food and Agriculture Organization of the United Nations, Rome.
4. Heeb, L., Jenner, E. and Cock, M.J.W. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science*, 92: 951–969. https://doi.org/10.1007/s10340-019-01083-y
5. Ma, C.S., Wang, B.X., Wang, X.J., Lin, Q.C., Zhang, W., Yang, X.F., van Baaren, J., Bebber, D.P., Eigenbrode, S.D., Zalucki, M.P., Zeng, J. and Ma, G. (2025). Crop pest responses to global changes in climate and land management. *Nature Reviews Earth & Environment*, 6: 264–283. https://doi.org/10.1038/s43017-025-00652-3
6. Pushpalatha, R., Gangadharan, B., Thendiyath, R. and Kutty, G. (2024). Potential distribution of rice thrips (Stenchaetothrips biformis) in India under changing climate. *International Journal of Pest Management*, 1–12. https://doi.org/10.1080/09670874.2024.2410179
7. Sahoo, S., Govindharaj, G.P.P., et al. (2026). Predicting habitat suitability of brown planthopper, Nilaparvata lugens (Stål), in India based on CMIP6 projections. *Annals of Applied Biology*. https://doi.org/10.1111/aab.70075
8. Skendžić, S., Zovko, M., Živković, I.P., Lešić, V. and Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects*, 12(5): 440. https://doi.org/10.3390/insects12050440
9. Tetarwal, O., Ghanswa, R., Chopra, N., Ghaswa, R. and Jat, G.R. (2026). Climate-driven range shifts in insect pests: Redrawing the global map of crop vulnerability. *Journal of Global Agriculture and Ecology*, 18(3): 132–145. https://doi.org/10.56557/jogae/2026/v18i310845
10. Tonnang, H.E.Z., Sokame, B.M., Abdel-Rahman, E.M. and Dubois, T. (2022). Measuring and modelling crop yield losses due to invasive insect pests under climate change. *Current Opinion in Insect Science*, 50: 100873. https://doi.org/10.1016/j.cois.2022.100873