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Climate change and crop protection: Toward a Climate-Smart Pest Management practices for food security

Muhammad Hammad Shad[1], Muhammad Sebtain Arshad[1], Muhammad Afzaal[1], Aqsa Jameel[2] and Muhammad Hamza[1]

1. Department of Entomology, University of Agriculture, Faisalabad
2. Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad

*Corresponding Author: **umeramer59@gmail.com**

ABSTRACT

Climate smart pest management (CSPM) sets up integrated pest management practices within climate smart agriculture to reduce pest induced crop losses, strengthen farm and land scape resilience to climate change and decrease greenhouse gas intensity per unit of food. The effective CSPM needed to coordinate action across farmers, extension departments, research policy and finance sectors. Development of toolbox of preventive agroecological practices, monitoring and forecasting or resilient varieties and an enabling environment are required that reward adoption. This present study enclosed the need for CSPM practices, key benefits, core components and toolbox, and innovative technologies that affect CSPM. This study also provides an insight into policies that enable environment protection. In conclusion, CSPM reframes pest management as an essential, cross sectoral component of climate smart agriculture that simultaneously advances food security, adaptation and mitigation. Scaling CSPM requires political leadership, investment in surveillance and forecasting, breeding for resilient cultivars, finance mechanisms and gender responsive extension.

Keywords: Climate, Change, Insects, Management practices, Pests, Smart

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Introduction

Climate smart pest management is a multi-disciplinary, cross-sectional approach, that systematically aligns insets pest management with 3-CSP goals, including sustainability to enhance productivity, strengthening resilience (adoption) and reduced greenhouse gas emissions if/where possible. It clearly consolidates numerous Integrated pest management (IPM) recommendations and climate matters into one action-oriented framework, which contributes to food security by decreasing insect pest intensity and reducing greenhouse gas emissions intensity. CSPM identifies that climate change is reforming insect pests' behavior (how pests behave) where they live, how fast they spread and how severe their outbreaks can become. It also emphasizes the importance of reducing current crop losses (approximately reached 40% already throughout the world) and adopting strategies which diminish further/ new invasions. Its implementation extends on farm activities, encouraging functions (research and extension) and facilitating conditions (such as infrastructure, finance and policy), so it is not only liked by farmers activity it also a public private and collective responses of research policies [1, 2]. The CSPM approach focuses on farm resilience and landscape flexibility, minimizing co-benefits and coordination of multiple stakeholders.

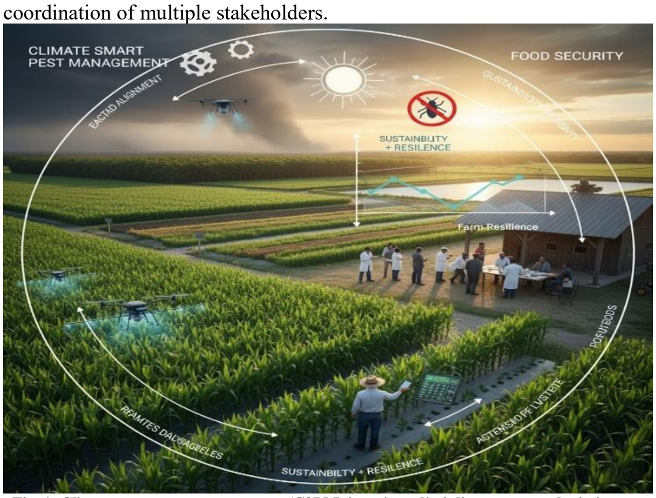

Fig. 1: Climate-smart pest management (CSPM) is an interdisciplinary approach aiming to increase resilience of farms and landscapes to chang- ing pest threats, mitigate greenhouse gas emissions and contribute to food security

Key benefits of adopting CSPM

Food security: by decreasing the unnecessary pest losses through enhancing prevention measures and detection. It enhanced yield and farm incomes for men and women. It strengthens households and national food security by providing food availability. Effective prevention reduced both emergency pesticide interventions and economic disruptions related to outbreaks [2].

Resilience and adaptation: CSPM decreased negative effect of pesticides on ecosystem services (such as natural enemies and pollinators). It also provides essential benefits to diversify agroecosystems that tolerate intense weather and pest pressure. Supporting extension, pest forecasting and surveillance at national scale is fundamental to adoptive capacity [3].

Mitigation and Co-benefits: CSPM reduced yield loss decreases the greenhouse gas emissions concentration per unit of production. Proactive measures like mulching, living barriers and minimal tillage help to storge carbon in soil and biomass while changing microclimate in ways that decrease certain types of insect's pest, it also establishes synergies between adaptations and mitigations. It prioritizes strategies that achieve multiple benefits and steers clear of approaches that improve resilience but enhance greenhouse gas outputs, for example through overuse of agrochemicals [3, 4].

Core components of Climate smart pest management

Farm-level agroecological practices: CSPM focuses on proactive, diverse practices such as Integrated pest management, conservation of natural enemies by managing habitat, intercropping and push-pull strategies. It also involves conservation of agricultural practices like decrease tillage and management of residue retention. Living barriers and mulches to decrease pressure of pressure of pests. It offers benefits by reducing carbon emission ultimately providing climate resilience. These practices change pest habitat, enhance natural control and decreased reliance on synthetic pesticides [3, 5].

Landscape and industrial elements: The incentives strategies are needed to scale CSPM beyond single farms, including area wide surveillance, early warning approaches, corresponding extension services, studying local pests' interaction with climate, and incentives like payments for ecosystem services or subsidies. The financing and actions for CSPM can be integrated into national commitments, for example NDCs [3, 4].

Practical approaches (Toolbox): CSPM approaches do not find completely novel approaches, while wraps proven methods of IPM and CSA practices in climate-responsive packages adapted to general scales and contexts, help them by providing training, development of seed bank of resilient varieties and financing to decrease adoption costs [1].

Monitoring, forecasting and digital decision approaches: Highly precision, predictive and monitoring tools are fundamental to anticipating CSPM. GIS system and habitat modelling can help to map insect pests and the risk related to them under certain climates and provides support to wide area for forecasting pest risks. The output of following system provides information about crop calendars and proactive interventions. Enhanced surveillance enables us for intime preventive measures and decreases overuse of insecticides [4].

Use of autonomous sensing and early warning systems consist of machine learning (for example adaptive classifiers+ WSNs+ GSM) that can detect climate changes and dynamics of pests (pest elevation) in real time, alter farmers in early time before the pest arrival for intime management. Studies exhibited that such systems could achieve maximum sensitivity, accuracy and specificity for the detection of insect pests' outbreaks. Enable intime interventions like non-chemical responses to decrease insecticide dependency. To maintain reliability, these approaches must be supported by effective extension and maintenance services [6].

Integrated resistance approaches (biotechnology and crop improvements)

To make sustainable CSPM approaches as core pillar, the innovations in plant breeding, genomics, formation of climate resilient and pest resistant cultivars can develop. Combining classical, transgenic and molecular methods can develop such types of crops that are enabled to sustain both in stress and under new climate regimes. These approaches decrease the need for external inputs as well as support sustainable IPM. The research in breeding strategies must consider the shifting of insect pests to alternative crops under high levels of carbon dioxide and temperature [7].

Biotechnologies (like BT crops for key insect pests) can be involved in integrated pest management approaches, but they must be used with proper governance to prevent or minimize resistance and non-target effects. Management of resistance must be supported by habitat-based approaches, including well designed protections. Continuous assessment of control tool efficacy under changing climate conditions is necessary [8, 9].

Interaction with Soil salinity and abiotic stress (implications for CSPM)

Climate change is increasing soil salinization due to rise in sea level, intrusion of saltwater, and increase in extraction of groundwater. The increase in salinity impairs crop vigor, pest alteration and dynamics in plant disease. This severely impacts the crop and shifts aptness of management decisions. Therefore, CSPM strategies like crops with stress tolerant genotypes and site-specific reclamation such as irrigation management, drainage and amendments etc. are also integrated with CSPM. The CSPM also emphasizes soil conservation to improve soil structure and water retention for sustainable agriculture. These integrated practices can impact the yield as well as also maintain insect pest populations by suppressing insect pest pressure [10].

In CSPM strategies relies on the cost-effective management practices rather than expensive de-salination technologies for agriculture sector. The planning and implementation of CSPM also includes soil salinity mapping and digital mapping of soil to prioritize the interventions where needed, for example during abiotic stress converge and to minimize pest risk [10, 11].

Enabling environment: finance, policy, gender and institutional arrangements

Strong political leadership and sustained public investment are critical, since CSPM relies on adequately resourced extension and research services to deliver pest forecasting, surveillance, and locally adapted management sets. Policy measures such as targeted subsidies and incentive frameworks can enhance the adoption of CSPM strategies, including both chemical less and low emissions practices. For example, the in China the green control policy is a working model pairing subsides for non-chemical users who control pests with extension support [3, 4].

Equality and gender: CSPM also offers support to women as they are the part of agriculture and produced food with low access to information and inputs. The CSPM design packages like training modalities, finance access and technical aspects for gendered preference and restraints. For example, studies showed that low-cost push-pull technologies are mainly acceptable by women and used efficiently when planned with sensitivity of genders [9]. To lower farmers fear of risks toward novel CSPM methods and underwrite adoption costs, the private sector, producers' associations and insurance or financial services could be utilized.

Practical implementation of CSPM

Create multi-stakeholder forums that connect agricultural, climate and environmental units to incorporate CSPM in national adaptation/mitigation planning and NDC implementation to establish coordination and leadership approaches [1, 4]. Finance in early warning systems, GIS/niche models, surveillance, decision support, forecasting, and sensor networks. Integrate the results into crop calendars and extension warning. Enhanced your abilities for data authority and maintenance [6]. Promote IMP packages that incorporate habitat management, conservation agriculture, push, pull and other context-appropriate preventive measures through farmer field schools and public incentives in order to scale up agroecological prevention [4, 9]. Assure seed systems for hardy cultivars. Encourage research and breeding: give priority to studies on the interactions between pests and climate, model pest range shifts and expedite the breeding of cultivars that are resistant to pests and abiotic stressors. Examine the effectiveness of control strategies in light of shifting climates. Financing and incentives: create cost-sharing plans, performance payments, or targeted subsidies to reduce adoption risk; link payments to observable adaptation or mitigation results [10]. The monitoring, assessment and modification given by CSPM in accordance with the results of randomized trials and long-term monitoring to assess the yield, intensity of GHG, ecosystem services, impacts gender and economic returns.

Research Gaps

- More effective models that deal with both crop phenology, pest biology and dynamics of climates are needed to develop.
- Efficacy of IPM strategies in future climate changes should be tested. There are few labs available which test performance of IPM components, biopesticides, biocontrol agents and other classical control methods under high carbon dioxide temperature and moisture content. These studies must be performed at both national and international levels.
- In CSPM the cost-effective soil salinity packages should be provided. There is an urgent need for practical research comparing combinations of nutrients, drainage, conservation techniques and salt tolerance genotypes.
- Socioeconomic and gendered acceptance pathways: improved data on financing methods, incentive schemes and gender specific extension strategies would hasten adoption and provide fair advantages.

Conclusions

CSPM reframes pest management as an essential, cross-sectoral component of climate-smart agriculture that simultaneously advances food security, adaptation and mitigation. Scaling CSPM requires political leadership, investment in surveillance and forecasting, breeding for resilient cultivars, finance mechanisms and gender-responsive extension. Priority actions are: mainstream CSPM in national climate and agriculture plans; deploy digital early-warning and GIS risk mapping; scale agronomic preventive bundles (IPM + conservation agriculture + agroforestry); and fill evidence gaps on tool efficacy and salinity-pest interactions. Implemented coherently, CSPM can reduce pest-driven losses, lower emissions intensity and strengthen resilient food systems under climate change.

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